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STREAM CHANNEL MORPHOLOGY IN NEW MEXICO: REGIONAL RELATIONSHIPS

Final Report

Submitted to

Rocky Mountain Experiment Station, Forest Service
United States Forest Service, Southwest Region
Under Contract # 28-JV7-955, Amendment #1

And

New Mexico Environment Department
State of New Mexico
Under Contract # 99 667 5000 0013

Submitted by

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December 1999

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Executive Summary

Over the past year a systematic study has been conducted on the geomorphology of seventy-five (75) reaches of streams and rivers in the State of New Mexico. Sites were chosen to represent a broad range of New Mexico's watershed types and sizes. Gaged and ungaged sites were included in the study. Both types of sites involved field data collection that included longitudinal profiles of the stream thalweg, water surface, and bankfull depositional features; cross-sectional profiles at riffle sections; and pebble counts of bed and bank materials at the riffle cross-sections. Parameters derived from these measurements included cross-sectional area, mean depth, width (all at bankfull stage), stream gradient, width-depth ratio, entrenchment ratio, sinuosity, and particle sizes D_{15}, D_{50}, and D_{84}. Analysis of gaged sites also included examination of the historical water record to determine flow return intervals, stage-discharge relationships, and site specific descriptive information.

After processing of the field measurements, data analysis focussed on the determination of regional relationships between watershed size and cross-sectional geometries and bankfull discharge, and on determination of the magnitude and frequency of the bankfull, or channel-forming, flows. Additionally, an attempt was made to identify hydrophysiographic sub-regions or provinces.

The data showed that a very strong correlation exists between watershed size and bankfull channel cross-sectional area for the state as a whole. Watershed size is also a determinant of bankfull discharge, mean depth, and width, but apparently not as strongly as it influences channel cross-sectional area. Streamside vegetation and geology likely have significant influence on these parameters. The average return interval of bankfull, or channel-forming, discharges, is approximately 1.5 years statewide. However, the lower, arid regions in the south appear to have smaller return intervals (~1.3 years), and the higher, mountainous regions in the north have slightly higher return intervals (~1.7 years). For field use of these regional curves, the whole state of New Mexico can be viewed as one hydrophysiographic province. However, the study area was subdivided into seven preliminary sub-regions, which should be clarified with additional field work. Analysis of the data within the sub-regions generally yielded slightly stronger correlations between watershed size and cross-sectional area. The sub-regions are Cimarron/Upper Pecos, Chama/Taos/ Jemez, Zuni Mountains, Chaco/San Juan, Upper Gila, Lower Rio Grande, and Lower Pecos.

Additional study of New Mexico's stream geomorphology should focus on the southern and eastern parts of the state. A coordinated collection and management of the state's stream geomorphology and hydrology database, augmented with local regional curves and reference reach information, should be undertaken by one or more of the relevant government agencies. This will be an invaluable resource for land managers, professionals, and researchers for restoration, engineering, habitat enhancement, and other projects in the rivers and streams of New Mexico.

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Introduction

The work described in this report was conducted by personnel in the Water Resources Engineering Laboratory, which operates within the Department of Civil and Environmental Engineering at Northern Arizona University in Flagstaff, Arizona. The work was funded by the U.S. Forest Service Southwest Region (USFS Contract #28 JV7-95 through the Rocky Mountain Research Station and by the New Mexico Environment Department (Contract #99 667 5000 0013).

Project Description

This project involves the investigation of stream geomorphology in selected watersheds in New Mexico. Gaged and ungaged streams were selected to establish regional relationships between watershed size (area) and certain parameters which are indicated by consistent, predictable depositional features. These features are related to and formed by bankfull discharge, or the channel-forming and maintenance discharge (Dunne and Leopold, 1978). Bankfull discharge has been strongly correlated with effective discharge, which is the discharge that carries the greatest amount of sediment over time (Wolman, 1960; Andrews, 1981). Other studies have shown a positive correlation between watershed size and parameters such as bankfull cross-sectional area, bankfull mean depth, bankfull width, and bankfull discharge (Leopold, et al 1964; Emmett, 1975; Jackson, 1994; Rosgen, 1996; Castro, 1997; Moody and Odem, 1999). Kelson and Wells, 1989, showed that lithology had an effect on the magnitude, timing, and duration of discharge in northern New Mexico. Other watershed characteristics such as elevation, rainfall, and gradient also likely affect discharge and therefore channel characteristics. Graphical representations of these relationships between watershed area and channel properties, regional curves, are useful tools for land managers, owners, researchers, engineers, and others doing restoration, planning, and other work related to and/or impacting streams and rivers. The data gathered through this project provide the basis for the regional curves developed for the State of New Mexico.

Site Locations

The data presented in this report were collected at streams throughout most of the state of New Mexico (Figure 1) except for the approximate eastern quarter of the state. Sites were chosen to represent most of New Mexico's watershed types. Gaged streams were chosen in consultation with representatives of the funding agencies. Ungaged streams were chosen by NAU personnel to provide greater breadth in watershed size in areas already defined by the gaged sites.

Methodology

Both gaged and ungaged sites were studied for achieving the project's objectives. Field collection of data was similar for both types of sites, while historical hydrological data was available only for the gaged sites. Of the 75 sites included in this study, 25 were gaged sites and 50 were ungaged sites. In the arid southwest there are many streams that do not flow year round. In this study there were 38 perennial streams, 32 ephemeral streams, and 5 intermittent streams. A list of the stream sites, locations, watersheds and flow types is presented in Table A1. Figure 1 shows locations of the study sites.

Gaged Sites

Gaged sites are critical to this type of work in order to relate historical hydrological data, especially flows, stages, and flow frequencies, to depositional features identified in the field. Gages chosen for this study are operated by the U.S. Geological Survey (USGS). Criteria for gage selection included the existence of an adjustable, or self-formed, alluvial channel, the existence of at least ten years of water record, and a currently active status, i.e. currently operated and maintained by the USGS.

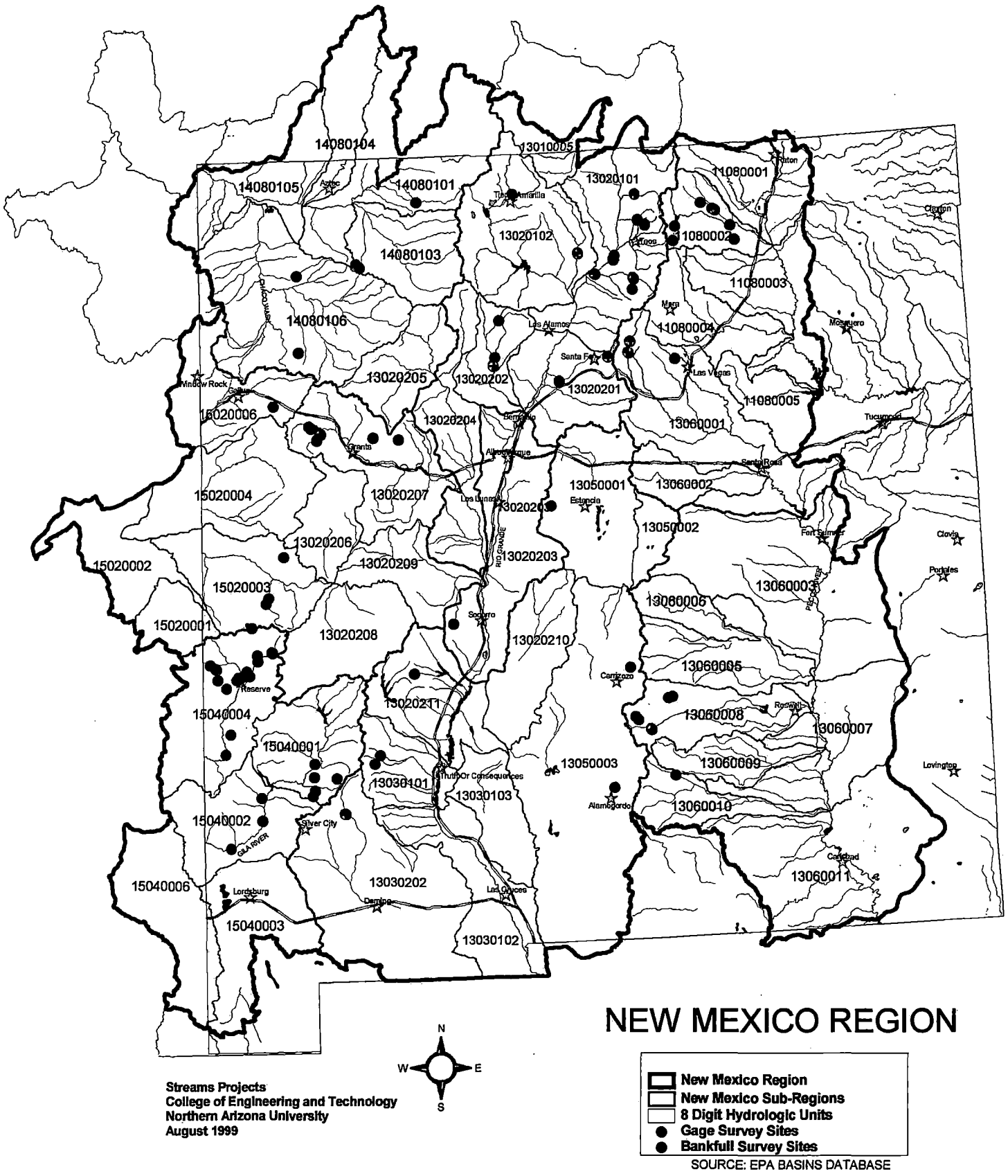
Hydrological Data

Existing historical hydrological data was collected for each gaged site. This information included station description, ratings tables, measured data (Form 9-207), and annual instantaneous peak discharges. Peak discharges were analyzed using the Weibull plotting position equation with a Pearson Type III distribution (USGS, 1981). This created an annual flood series frequency distribution from which flow return intervals could be estimated.

Field Collection of Data

At each gage site a length of stream reach equal to approximately 20-40 bankfull widths was approximated. Along this reach depositional features, terraces, vegetation and other features were noted. A Topcon GTS-200 Electronic Total Station, linked with a Hewlett-Packard 48 GX Data Collector and TDS Survey Card, was used to measure the longitudinal profile of the stream along with 3-5 cross-sections at stream riffles. The longitudinal profile included both the channel thalweg and, when present, the water surface. Cross-sections were extended to an elevation on both banks representing at least twice the maximum bankfull stream depth. Depositional features, terraces, and other features were also surveyed along the stream reach. The survey was tied into existing reference benchmarks at the gage itself. Selected cross-sections were staked to provide permanent stationing for monitoring purposes. Bed and bank materials were characterized at each cross-section using the Wolman Pebble Count Method (Harrelson et al, 1994).

Figure 1. Location of Study Sites



Ungaged Sites

Field Collection of Data

Data collection at ungaged sites followed the same procedures as described above for gaged sites except that a laser level and measuring tape were used to collect elevation and distance information instead of the total station. Slope was measured along the channel profile of each stream reach. A single cross sections was measured at the ungaged sites along with accompanying pebble counts.

Data Analysis

The gage site survey data was processed with either Eagle Point Surveying Software and imported into AutoCAD for calculations and graphical manipulations, while ungaged site data was processed with Microsoft Excel. The data was displayed in plan, profile and cross-section formats. Calculations were performed to determine slope, sinuosity, cross-sectional area, mean depth, maximum depth, width, flood prone width, width-to-depth ratio, and entrenchment ratio. Pebble counts were evaluated to determine the distribution of particle sizes and the following specific sizes: D_{15}, D_{50}, and D_{84}. Classification of the stream reach was done using the Rosgen classification system (Rosgen, 1994). Cross sections and depositional features were evaluated to determine consistency in bankfull determinations and to evaluate bankfull slope, which was compared with water surface and thalweg slopes. The bankfull slope line was also connected to the gage to determine the elevation of bankfull discharge at the gage. This allowed determination of discharge by comparing this elevation, or stage, with the ratings table. An estimate of flow return interval was then possible by using the flow frequency distribution created with the historical gage data. Estimations of flow velocity and channel roughness (Manning's 'n') were made for gaged sites based on stage-velocity relationships, which were obtained from 9-207 forms.

Statisitical data analysis compared watershed area, an independent variable, against bankfull channel width, mean depth, and cross-sectional area, and against the estimated bankfull discharge. The data were best described using a non-linear model, a power function, which is described by

$$\mathbf{y = ax^B.}$$

where y is the predicted value (area, depth, width, or discharge) , x is the independent variable watershed size, and a and B are adjustable coefficients that characterize a data set. For ease of parameter estimation, the model is linearized by a logarithmic transformation of the equation to obtain

$$\mathbf{\log(y) = \log(a) + B\log(x)}$$

B and log(a) are given by the slope and intercept of the best fit line. The power function model plots as a straight line on log-log graphs. The strength of the fit was evaluated with

the coefficient of determination, r^2. Regional curves were created on log-log graphs by plotting watershed area against bankfull cross-sectional area, bankfull width, bankfull mean depth, and bankfull discharge An initial division of the study area into sub-regions or provinces was attempted based on obvious differences in physiographic properties coupled with regression analyses. However, to properly and definitively identify sub-regions in the state would require further analysis to evaluate such watershed properties as geology, topography, and climate.

Results and Discussion

A summary of all site channel data is presented in Appendices A1, A2, and A3. Site drawings based on survey data are included as a second volume, to be included with the Final Report. These drawings include plan views, longitudinal profiles, cross-sectional profiles, and bed and bank material information.

Regional Curves

The data from seventy-five study sites were used to develop a regional relationship between bankfull channel geometry and watershed area. The study area was divided into Hydrologic Units, which are discreet geographical units organized around watershed boundaries and identified by Hydrologic Unit Codes (HUCs). HUCs are assigned by the USGS and have been established for all of the watersheds within the United States. They are commonly used by water resources professionals in government agencies and private practice. Grouping by HUCs was done for two reasons. First, channel maintenance flows are a function of the climate, topography, and geology of a watershed. These characteristics can be expected to be shared within individual or adjacent watersheds. Second, a goal of this project is to develop a tool that will aid in field identification of bankfull stage. HUCs provide a consistent and common geographical unit based on watershed that allows easy field site identification.

The strength of the relationships between bankfull channel geometry and watershed area was tested by plotting cross-sectional area at bankfull stage against watershed area. Cross-sectional area has less variability than either width or depth across a range of channel shapes, and is easily measured in the field.

For all of the New Mexico study sites as a whole, watershed area appears to be a good predictor of stream cross-sectional area. Figure 2 shows a log-log plot of these two parameters for all sites with the best-fit line drawn in. A high positive correlation coefficient of 0.90 indicates that this statewide regional curve can be reliably used in the field to estimate bankfull stage, given watershed size. Figures 3 & 4 show watershed size against width and mean depth, respectively. These relationships are not as strong as for cross-sectional area, indicating greater variability and thus less predictability. However, the relationships are still strong enough to imply some utility for fieldwork. Figure 5 shows the relationship between watershed size and bankfull discharge for the 25 gaged sites. Watershed area is generally a good predictor of bankfull discharge. Further analysis

of the project data with respect to underlying lithology could possibly refine this relationship for different geologic regions.

Further classification of the study sites into smaller hydrophysiographic units requires not only identification of likely physiographic boundaries, but a compelling argument with respect to watershed characteristics (e.g. elevation, geology, rainfall) along with stronger statistical correlations as evidenced by the data. In general, it is more useful for regional curves to cover as large an area a reasonably supported by the data. This also increases the number of sites and therefore the reliability of the database statistics. However, it should be stressed that for those working with streams, it is important to develop local channel geometry curves that describe the area of work. Stream channel design work should further incorporate site-specific reference reaches for a necessary level of confidence in channel geometries.

Hydrophysiographic sub-regions are proposed herein. These are classified as sub-regions with the whole state of New Mexico identified as the major hydrophysiographic region or province. These sub-region classifications are based primarily on climatic and/or physiographic characteristics of basins. Statistical correlations don't improve significantly over treatment of the database as a whole. Without an increase in numbers of sites per sub-region and further analysis of the current data with respect to climate and geology, these proposed classifications are provisional.. Nevertheless, these classifications are presented for two reasons: 1) they may prove useful to field workers; 2) they may in fact represent distinct sub-regions, which can be ascertained by future research.

The sub-regions are described and shown in Appendix B and include the relevant data and map locations. They are identified as follows: Region A – Cimarron/Upper Pecos Region; Region B – Chama/Taos/Jemez Region; Region C- Zuni Mountains Region; Region D – Chaco/San Juan Region; Region E – Upper Gila Region; Region F – Lower Rio Grande Region: Region G – Lower Pecos Region.

Figure 6 shows the New Mexico regional curves for stream cross-sectional area compared with regional curves for other areas in the western U.S. Recent work from Arizona (Moody and Odem, 1999) shows a line with similar slope, but higher position, indicating a larger cross-sectional area for the same watershed size.

Figure 2. Bankfull Cross-Sectional Area as a Function of Watershed Area, All New Mexico Sites

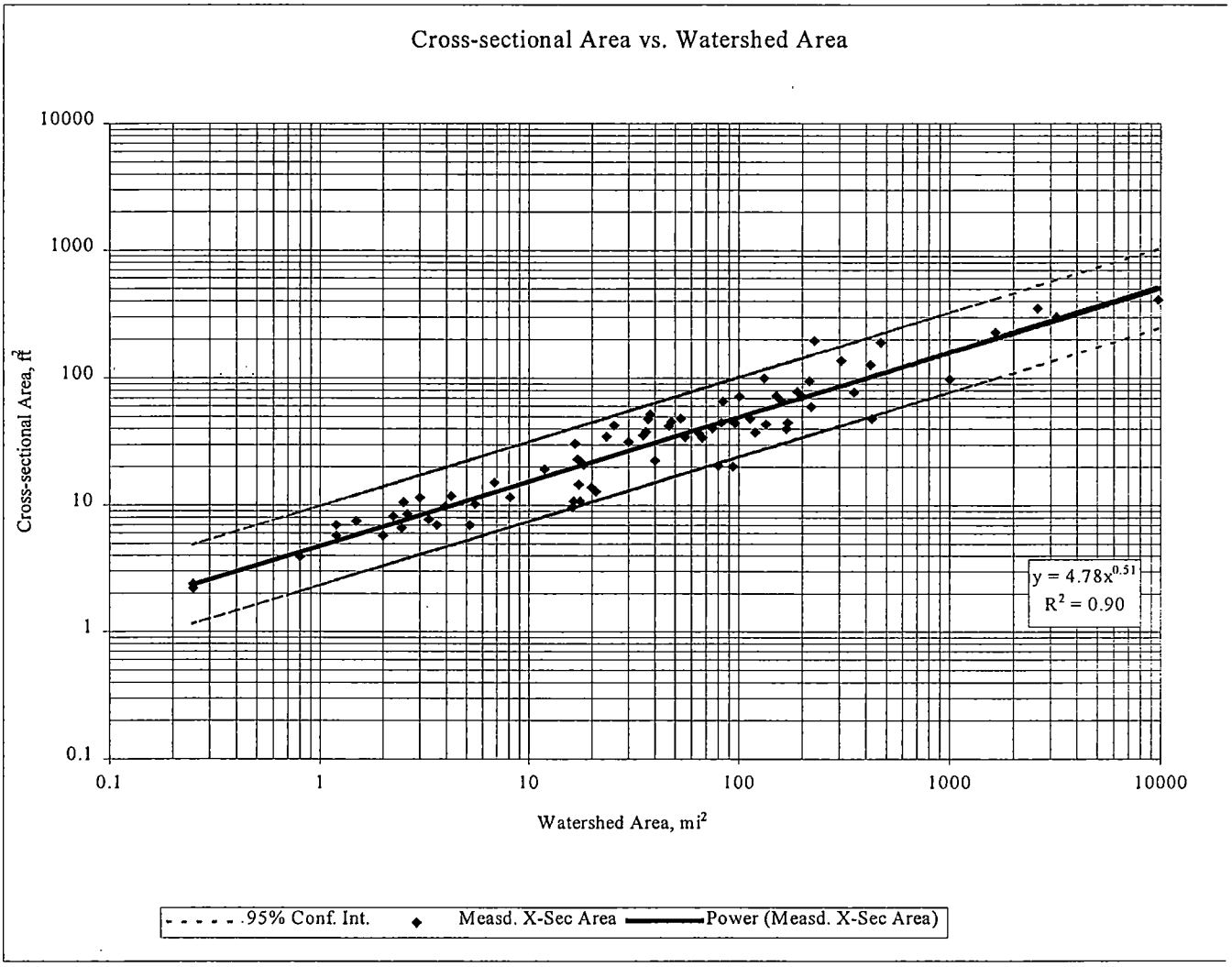


Figure 3. Bankfull Width as a Function of Watershed Area, New Mexico

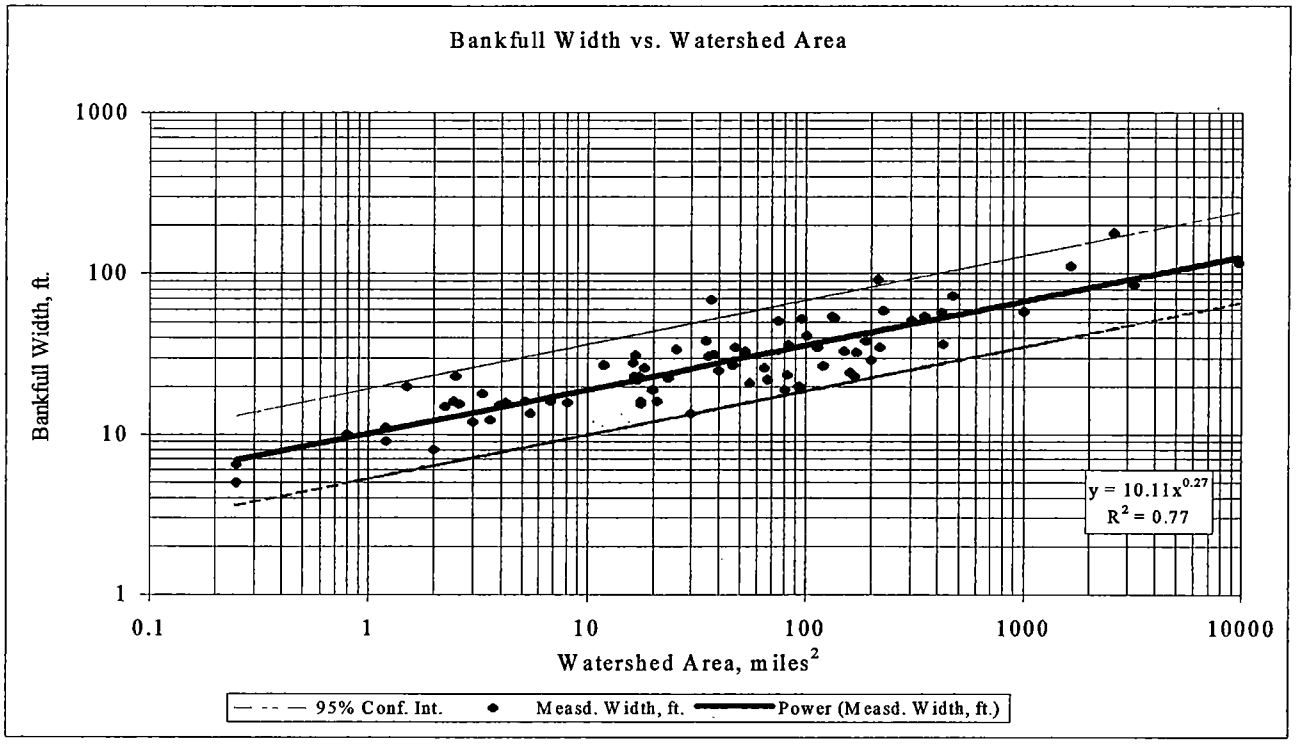


Figure 4. Mean Depth as a Function of Watershed Area, New Mexico

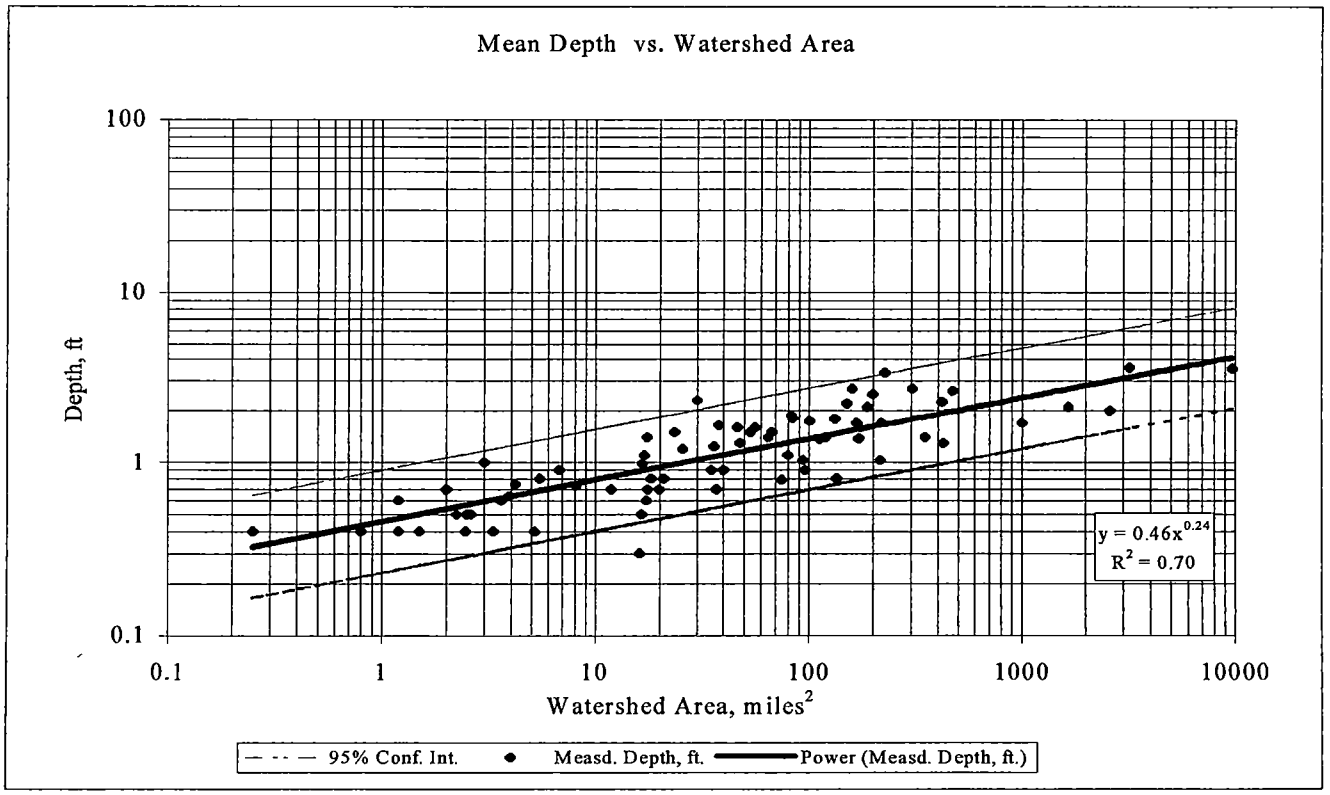


Figure 5. Bankfull Discharge as a Function of Watershed Area, New Mexico Gage Sites

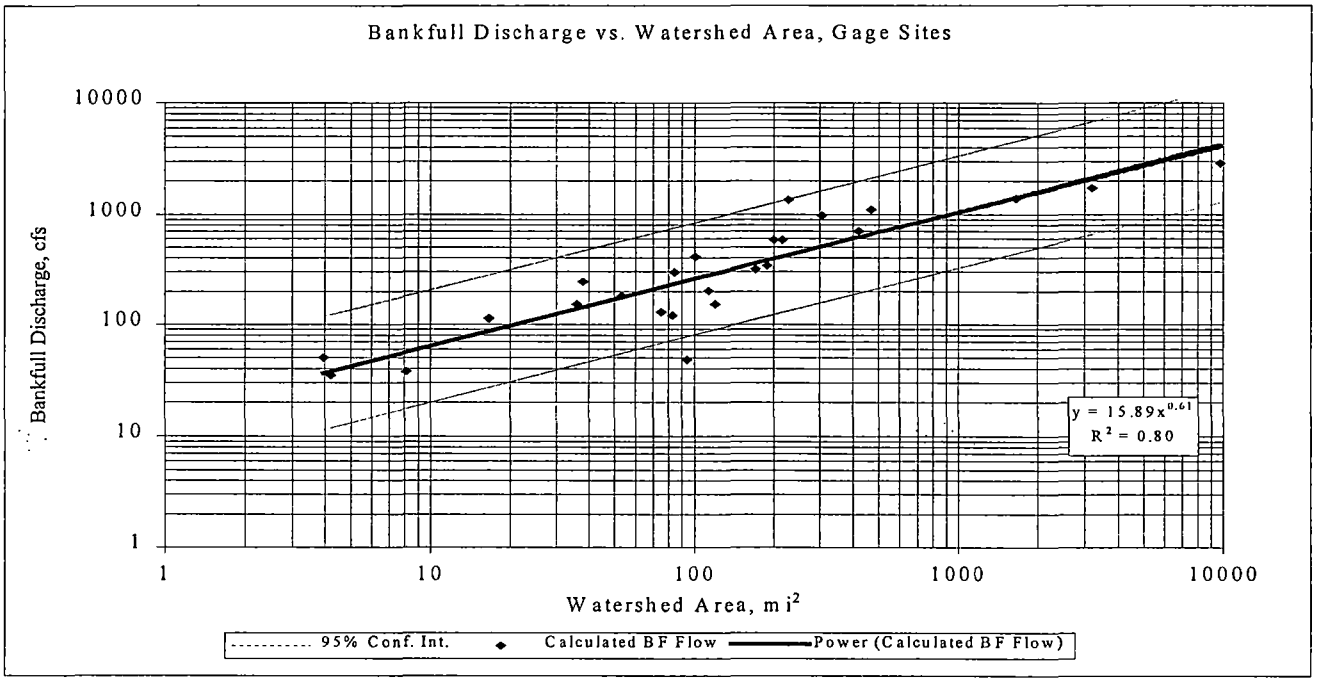
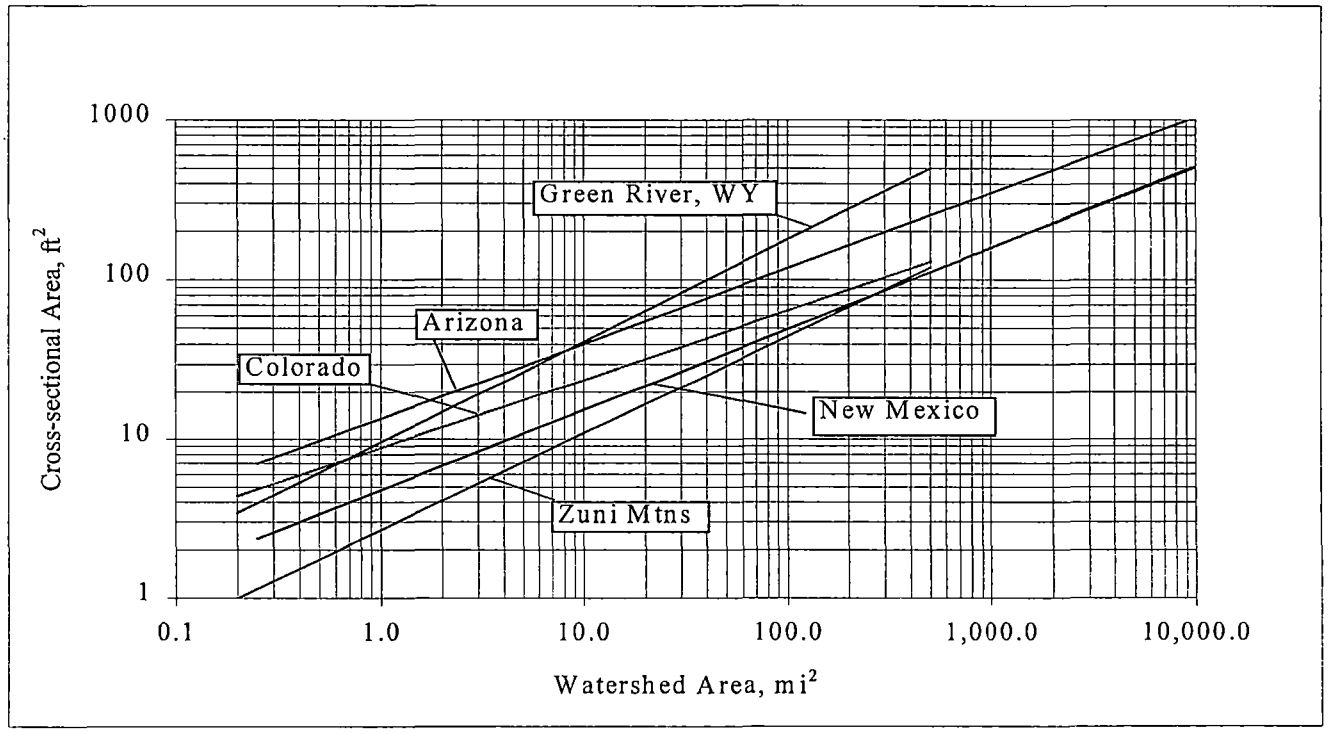


Figure 6. Regional Curves from the Western United States



(Refs: Leopold et al, 1964; Emmett, 1975; Jackson, 1994; Moody and Odem, 1999)

Flow Recurrence Intervals

Bankfull flow recurrence intervals (the statistically derived time interval expected between bankfull flows or higher), determined at the 25 gaged sites, ranged from 1.0 to 1.8 years with an average of 1.52 years. These values are consistent with data from other parts of the country (Leopold, et. al., 1964; Castro, 1997; Moody and Odem, 1999). However, trends were noted in the different physiographic regions of the state. In the higher elevation, steeper, mountainous regions (around Taos), the return interval averaged 1.66 years (11 gaged sites), while in the lower elevation, lower gradient regions, e.g. in the lower and upper Pecos basins, return intervals averaged 1.4 years (6 sites). In the Upper Gila region, return intervals averaged 1.3 years for the 6 gaged sites in that area. Return flow values are shown in Table 1. Use of return intervals, however, to estimate bankfull or channel-forming discharges, should only be done with corroborating field evidence.

Table 1. Return Intervals for New Mexico Sub-regions.

Region	Mean value (years)	Range (years)	# of sites
Cimarron/upper Pecos	1.5	1.3 – 1.7	4
Chama/Taos/Jemez	1.7	1.4 – 1.8	11
Chaco/San Juan	-	-	0
Zuni Mountains	1.7	1.7	1
Upper Gila	1.3	1.0 - 1.6	4
Lower Rio Grande	1.5	1.5	1
Lower Pecos	1.4	1.4	2

Mean Depth, Mean Velocity, Roughness

The ability to accurately estimate cross-sectional area is important to the identification of bankfull stage in the field. While channel width can be directly measured, mean depth is a calculated value. Maximum channel depth, however, can also be directly measured. A reasonably accurate value for cross-sectional area can be estimated by using the relationship between maximum depth and mean depth. Figure 7 show maximum depth vs. mean depth for all of the New Mexico sites and the best fit line for the data. Therefore, to estimate bankfull cross-sectional area in the field, the following equation can be used:

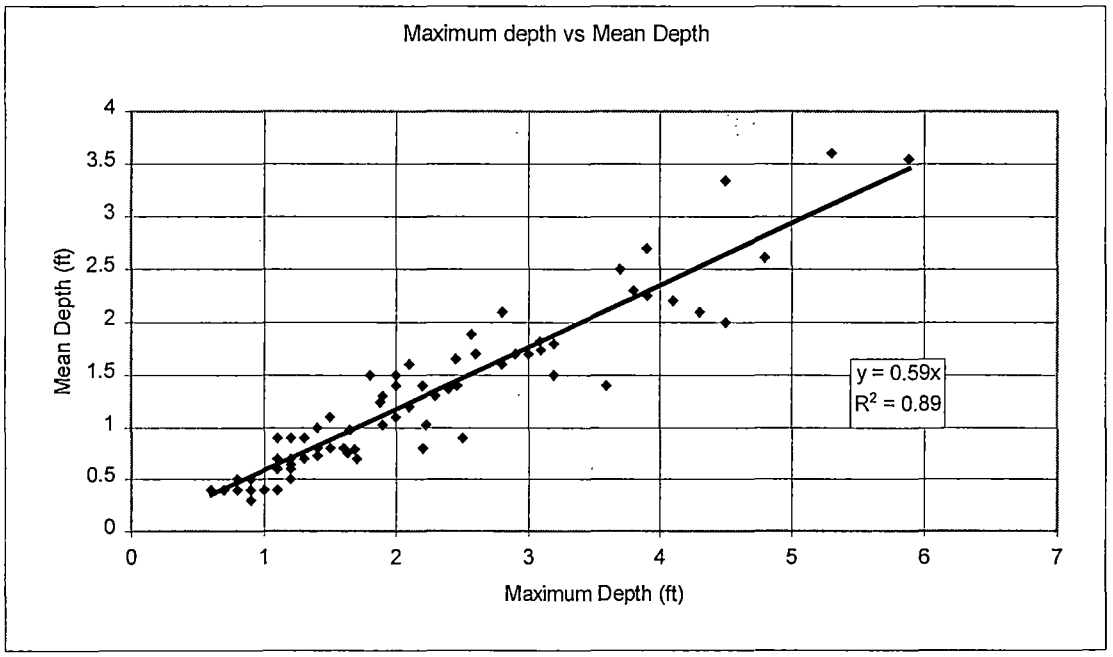
$$A_{xs} = W_{bf} \times D_{max} \times 0.6$$

(A, W, and D stand for area, width, and depth, all measured at bankfull.) This relationship holds only for riffle sections and should be verified by detailed measurements.

For purposes of hydraulic analysis, it is useful to have estimates of velocity and/or channel roughness. The majority of mean bankfull velocities ranged from 3 to 7 feet per

second, while most of the channel roughness values (Manning's 'n') ranged from 0.02 to 0.06. These data are included in Appendix IIB for all of the gaged sites. Site specific estimates for velocity and roughness can be made using locally developed curves and tying them in with associated gage data. The 9-207 data collection forms also give measured velocities at different stages, which can then be used to estimate roughness.

Figure 7. Mean Depth vs. Maximum Depth at Bankfull Stage



Stream Channel Types

All of the stream reaches investigated in this study were classified according to the Rosgen stream classification scheme (Rosgen, 1994). This classification utilizes certain delineative criteria to classify streams: stream gradient, sinuosity, width-depth ratio, entrenchment ratio, number of channel threads, meander width ratio, and bed and bank material. Figure 8 shows the breakdown in stream types identified in this study. Appendix IC lists all of the data and the classifications for all study sites.

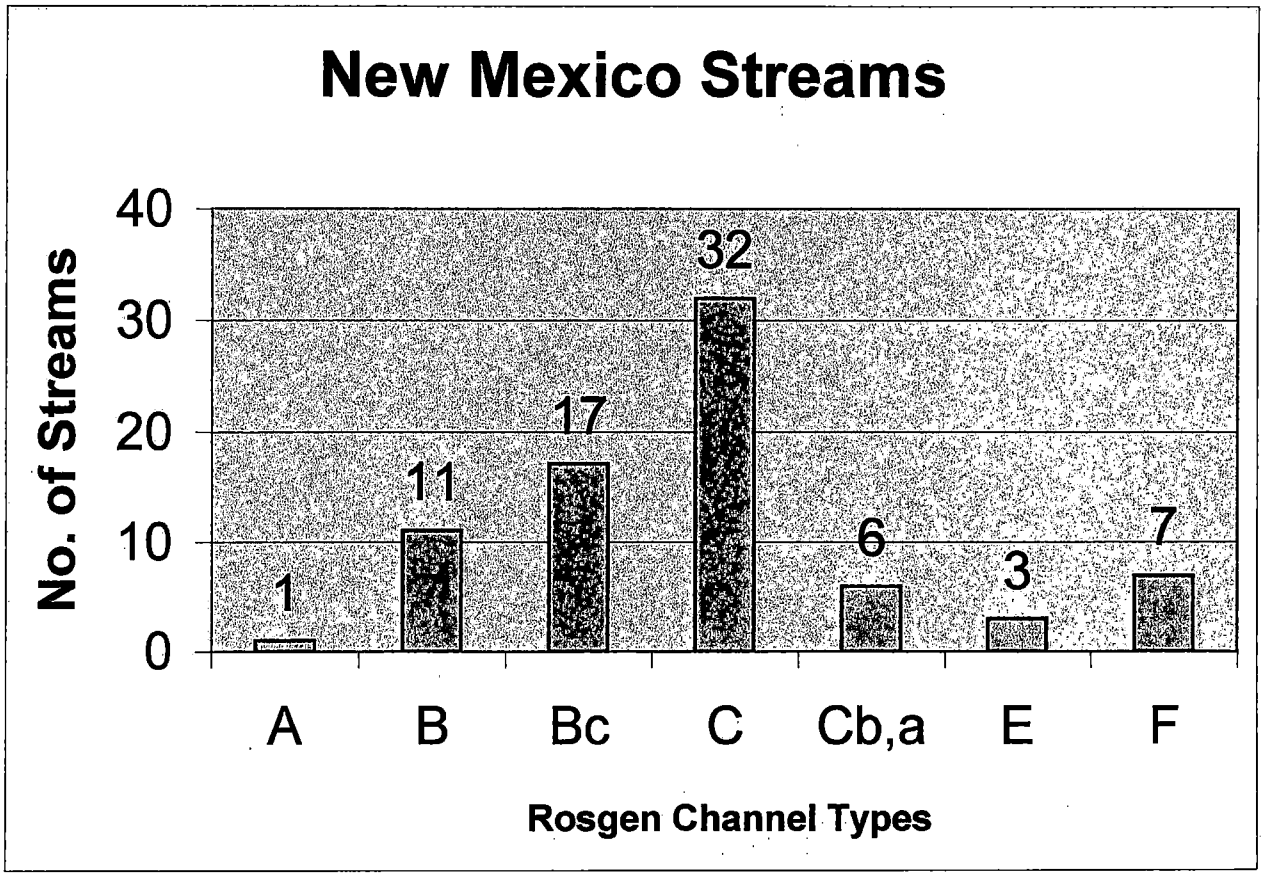
Thirty-two (32) of the streams investigated were C type channels. These channels are characterized by moderate sinuosity and gradient, well developed point bars, and readily accessible floodplains for energy dissipation. They are typically viewed as a stable channel type, unless they are in a process of degradation from an E type channel. In addition to the standard C type streams, there were six study reaches that showed characteristics of C streams except for higher stream gradients, i.e. greater than 2%.

These were identified as C_b or C_a streams due to their high entrenchment ratio (access to floodplain) and/or sinuosity. (Note: high entrenchment ratio implies a low entrenchment condition, while a low entrenchment ratio implies an entrenched condition.)

Twenty-eight (28) of the stream reaches were classified as B channels, which have a relatively high gradient, moderate entrenchment ratio, low sinuosity, and a pool-drop profile. Seventeen (17) of these reaches classified as B_c, which indicates a B type channel with a gradient typical of C channels, i.e. less than 2%. These channels appear to be stable, and, as determined in Arizona (Moody et al, 1999), they are not uncommon. This may in fact be a stable channel type typical for higher elevation arid climates.

Seven of the stream reaches were classified as F channels, which are typically unstable, with high width-to-depth ratios and no access to a floodplain. Three E type channels were identified, which are stable with low width-to-depth ratios, high sinuosities, and typically low to moderate gradients. One A type channel was identified, a type usually found in mountainous regions.

Figure 8. Rosgen Channel Types.



Conclusions

Data were collected from seventy-five (75) stream reaches in New Mexico to investigate the relationship between channel geometry and watershed size and to tie in historical water records with channel properties. Analysis of the data showed that watershed size is an important controlling parameter in channel cross-sectional geometries and magnitude of bankfull, or channel-forming, flows. A strong correlation between watershed size and channel cross-sectional area exists for streams from the whole state, allowing reliable use of single regional curve throughout New Mexico. The correlations with other channel parameters , width and mean depth, were not as strong. Watershed size is also a reasonable predictor of bankfull discharge. The average return interval for bankfull discharge is 1.52 years for the state as a whole, with slightly lower return intervals observed for the lower, arid regions in the southern part of the state and slightly higher intervals in the higher mountainous areas. Though subdivision of the study area into smaller hydrophysiographic provinces is unnecessary for purposes of regional curve development, a regional subdivision of the study area is proposed that identifies seven sub-regions. Additional work in these sub-regions can clarify their boundaries and identify controlling influences on watershed hydrology.

Recommendations

The regional curves developed in this study are useful field tools for work being done in the streams and rivers of New Mexico. They should be supplemented with local curves and reference reach data when stream restoration, engineering projects, habitat enhancement, or other work is being done. Additional study to enhance New Mexico's stream geomorphology database should focus on the southern and eastern parts of the state. More detailed analysis of watershed characteristics may determine other controlling factors in addition to watershed size. NMED or USFS or other agencies should coordinate the collection of stream channel data generated by those working on specific streams. This will give both additional breadth and depth to this database, and provide useful guidance for practicing professionals, land managers, and researchers.

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Appendix A: Study Sites

Appendix A1. Site Locations and Watersheds.

Table A1. Study Sites and Locations.

Site Name	Latitude	Longitude	Watershed	WS area (mi2)	HUC	Flow Type
Gaged Sites						
Bluewater Creek ab Bluewater Dam, NM	35 16' 04"	108 06' 50"	Middle Rio Grande	75	13020207	Perennial
Copperas Canyon nr Pinos Altos, NM	33 04' 42"	108 02' 14"	Upper Gila	3.95	15040001	Ephemeral
Duck Creek nr Cliff, NM	32 58" 03'	108 36" 36'	Upper Gila	228	15040002	Ephemeral
Eagle Creek Below South Fork nr Alto, NM	33 23' 33"	105 43' 16"	Lower Pecos	8.14	13060008	Perennial
Embudo Creek at Dixon, NM	36 12' 39"	105 54' 47"	Upper Rio Grande	305	13020101	Perennial
Gallinas Creek nr Montezuma, NM	35 39' 07"	105 19' 06"	Upper Pecos	84	13060001	Perennial
Gila River blw Blue Creek nr Virden, NM	32 38' 53"	108 50' 43"	Upper Gila	3202	15040002	Perennial
Jemez River nr Jemez, NM	35 39' 45"	106 44' 30"	Jemez	470	13020202	Perennial
Mail Hollow nr Luna, NM	33 47' 38"	108 56' 59"	San Francisco	4.2	15040004	Ephemeral
Mimbres River at Mimbres, NM	32 51' 17"	107 58' 53"	Lower Rio Grande	216	13030202	Perennial
Pecos River at Pecos, NM	35 42' 30"	105 40' 55"	Upper Pecos	189	13060001	Perennial
Ponil Creek nr Cimarron, NM	36 34' 35"	104 56' 46"	Cimarron	171	11080002	Perennial
Red River nr Questa, NM	36 42' 12"	105 34' 04"	Upper Rio Grande	113	13020101	Perennial
Rio Grande blw Taos Jct. Bridge, NM	36 19' 12"	105 45' 14"	Upper Rio Grande	9730	13020101	Perennial
Rio Grande del Rancho nr Talpa, NM	36 17' 52"	105 45' 55"	Upper Rio Grande	83	13020101	Perennial
Rio Hondo nr Valdez, NM	36 32' 30"	105 33' 21"	Upper Rio Grande	36	13020101	Perennial
Rio Lucero nr Arroyo Seco, NM	36 30' 30"	105 30' 00"	Upper Rio Grande	16.6	13020101	Perennial
Rio Mora nr Terrero, NM	35 46' 38"	105 39' 26"	Upper Pecos	53.2	13060001	Perennial
Rio Ojo Caliente at La Madera, NM	36 20' 59"	106 02' 37"	Chama	419	13020102	Perennial
Rio Pueblo nr Penasco, NM	36 10' 14"	105 36' 36"	Upper Rio Grande	101	13020101	Perennial
Rio Ruidoso at Hollywood, NM	33 19' 36"	105 37' 38"	Lower Pecos	120	13060008	Perennial
Rio Santa Barbara nr Penasco, NM	36 06' 13"	105 37' 14"	Upper Rio Grande	38	13020101	Perennial
San Francisco River nr Glenwood, NM	33 14' 48"	108 52' 47"	San Francisco	1653	15040004	Perennial
Santa Fe above Cochiti Reservoir, NM	35 32' 49"	106 13' 41"	Upper Rio Grande	200	13020201	Perennial
Santa Fe River nr Santa Fe, NM	35 41' 12"	105 50' 35"	Rio Grande	18.2	13020201	Perennial
Tularosa River ab Aragon, NM	33 53' 29"	108 30' 54"	Upper Gila	94	15040004	Perennial
Ungaged Sites						
Apache #2-East of Picture Tank	34 11' 59"	108 33' 02"	Little Colorado	2.45	15020003	Ephemeral
Apache Creek	33 50' 11"	108 37' 24"	Upper Gila	135	15040004	Intermittent
Apache Creek trib (Red Steer Canyon)	33 52' 27"	108 37' 32"	Upper Gila	2.24	15040004	Ephemeral
Bluewater Creek above FS campground	35 13' 46"	108 08' 20"	Middle Rio Grande	67.25	13020207	Perennial
Bluewater Creek trib.	35 13' 37"	108 08' 19"	Middle Rio Grande	3	13020207	Ephemeral
Cieniguilla Creek at Gage	36 29' 07"	105 15' 54"	Cimarron	56	11080002	Perennial
Cieniquilla Creek blw Angel fire	36 23' 38"	105 16' 59"	Cimarron	17.5	11080002	Perennial
Cimarron River blw Miami Lane	36 28' 13"	104 49' 38"	Cimarron	150.7	11080002	Perennial
Coal Mine Campground	35 14' 01"	107 41' 58"	Middle Rio Grande	5.18	13020207	Intermittent
Cottonwood Gulch	35 18' 59"	108 11' 56"	Middle Rio Grande	18.25	13020207	Perennial
Crownpoint#1 below Hwy.9 Bridge	35 47' 04"	108 16' 11"	San Juan	40	14080106	Intermittent
Dry Canyon	32 57' 31"	105 55' 35"	Tularosa Valley	11.9	13050003	Ephemeral
E Red Canyon	33 44' 00"	107 25' 46"	Lower Rio Grande	20.9	13020211	Ephemeral
Eagle Creek Trib #1	33 24' 38"	105 44' 29"	Lower Pecos	0.25	13060008	Ephemeral
East Fork Gila river at Grapevine Campground	33 10 36	108 12 02	Upper Gila	1000	15040001	Perennial
FS 547 Road - Cibola	35 26' 54"	108 28' 24"	Little Colorado	0.25	15020006	Ephemeral
Gila River at Bird Area	32 49' 17"	108 36' 25"	Upper Gila	2600	15040002	Perennial
Hunter Wash	36 16' 02"	108 16' 11"	San Juan	48	14080106	Ephemeral
Hwy 44, MP121	36 19' 44"	107 47' 58"	San Juan	2.5	14080103	Ephemeral
Hwy 44, MP123	36 18' 16"	107 46' 14"	San Juan	1.5	14080103	Ephemeral
Hwy. 12 outside Reserve	33 43' 08"	108 47' 11"	San Francisco	37.17	15040004	Ephemeral
Hwy. 32 below Apache Cr. (Largo Canyon)	33 46' 21"	108 42' 39"	Upper Gila	23.5	15040004	Ephemeral
Jct. 209 and 180	33 43' 19"	108 56' 06"	San Francisco	0.8	15040004	Ephemeral
Jemez River ab Rio Guadalupe, NM	35 42' 37"	106 43' 31"	Jemez	220	13020202	Perennial
Jewett Gap	34 02' 52"	108 39' 55"	Upper Gila	2	15040004	Intermittent
La Jara Arroyo, NM	36 42' 35"	107 18' 30"	San Juan	96	14080103	Intermittent
Middle Fork Ponil Creek	36 37' 23"	105 02' 58"	Cimarron	65	11080002	Perennial
Morgan Creek	33 09' 52"	107 44' 40"	Lower Rio Grande	17.56	13030101	Ephemeral
Mt. Taylor #1	35 13' 10"	107 30' 07"	Middle Rio Grande	1.2	13020207	Ephemeral
N Fork Palomas	33 13' 02"	107 42' 05"	Lower Rio Grande	16.1	13030101	Ephemeral
Pine Canyon - Cibola	35 18' 02"	108 10' 54"	Middle Rio Grande	5.5	13020207	Ephemeral
Ponil Creek above Gage	36 35' 00"	104 57' 37"	Cimarron	168	11080002	Perennial
Rayado Creek ab. Miami Lane	36 22' 42"	104 48' 09"	Cimarron	160	11080002	Perennial

Rio Bonito	33 30' 59"	105 29' 21"	Lower Pecos	80.29	13060008	Ephemeral
Rio Brazos @ County Rd. 573	36 44' 15"	106 32' 21"	Chama	132.34	13020102	Ephemeral
SA Canyon	33 10' 37"	108 12' 01"	Upper Gila	4	15040001	Ephemeral
Saliz Cr. Blw Wet and Dry Leggett	33 40' 03"	108 52' 08"	San Francisco	17	15040004	Ephemeral
San Antonio Creek	35 56' 27"	106 41' 01"	Jemez	46.6	13020202	Ephemeral
San Francisco nr Reserve (gage site)	33 44' 12"	108 46' 14"	San Francisco	350	15040004	Perennial
San Francisco River above Luna, NM	33 49' 05"	108 59' 27"	San Francisco	30	15040004	Perennial
Sandy Wash at Catron Billboard	34 29' 36"	108 24' 47"	Little Colorado	3.3	15020003	Ephemeral
Sixteen Springs Canyon	33 1' 19"	105 27' 29"	Lower Pecos	19.92	13060010	Ephemeral
Tajique Campground	34 45' 50"	106 19' 39"	Estancia Sink	17.27	13050001	Perennial
Trib to Copperas Canyon #1	33 05' 29"	108 12' 21"	Upper Gila	1.2	15040001	Ephemeral
Trib to Largo Cr.-Apache NF	34 13' 53"	108 31' 56"	Little Colorado	3.6	15020003	Ephemeral
Trib to Trout Creek on hwy 15	32 58' 17"	108 13 11	Upper Gila	2.6	15040001	Ephemeral
Tularosa River below Canyon	33 44' 34"	108 41' 15"	Upper Gila	426	15040004	Perennial
V1 Canyon	33 32' 17"	105 26' 13"	Lower Pecos	6.81	13060005	Ephemeral
Water Canyon	34 2' 24"	107 6' 52"	Middle Rio Grande	16.4	13020209	Ephemeral
White Oaks Draw	33 43' 17"	105 46' 01"	Tularosa Valley	25.58	13050003	Ephemeral
Whitewater Creek at Catwalk	33 22' 25"	108 50' 25"	San Francisco	35	15040004	Perennial

Appendix A2. Site Data.

Table A2. Channel Geometry and Hydrology Data.

SITE NAME	WATER-SHED AREA (mi^2)	X-SECT AREA (ft^2)	WIDTH (ft)	MEAN DEPTH (ft)	MAX DEPTH (ft)	VELOCITY (fps)	MANNING'S n	FLOW (cfs)	RETURN INTERVAL (years)
Apache #2-East of Picture Tank	2.45	6.6	16	0.4	0.8				
Apache Creek	135	43.5	53	0.8	1.6				
Apache Creek trib (Red Steer Canyon)	2.24	8.2	15	0.5	0.9				
Bluewater Creek ab Bluewater Dam, NM	75	40.3	50.88	0.79	1.68	3.2	0.012	129	1.7
Bluewater Creek above FS campground	67.25	34	22	1.5	3.2				
Bluewater Creek trib.	3	11.44	12	1	1.4				
Cieniguilla Creek at Gage	56	34.4	21	1.6	2.8				
Cieniquilla Creek blw Angel fire	17.5	22.42	15.5	1.4	2				
Cimarron River blw Miami Lane	150.7	73	33	2.2	4.1				
Coal Mine Campground	5.18	7	16	0.4	0.9				
Copperas Canyon nr Pinos Altos, NM	3.95	9.8	15.2	0.64	1.2	5.1	0.159	50	1
Cottonwood Gulch	18.25	21	26	0.8	2.2				
Crownpoint#1 below Hwy.9 Bridge	40	22.65	25	0.9	2.5				
Dry Canyon	11.9	19.28	27	0.7	1.2				
Duck Creek nr Cliff, NM	228	196	58.9	3.34	4.5	6.9	0.042	1350	1.1
E Red Canyon	20.9	12.95	16	0.8	1.5				
Eagle Creek Below South Fork nr Alto, NM	8.14	11.59	15.78	0.73	1.4	3.3	0.054	38	1.4
Eagle Creek Trib #1	0.25	2.2	5	0.4	1.1				
East Fork Gila R. at Grapevine Campground	1000	98.4	58	1.7	3				
Embudo Creek at Dixon, NM	305	137.7	51.1	2.7	3.9	7.1	0.038	976	1.8
FS 547 Road - Cibola	0.25	2.38	6.5	0.4	0.7				
Gallinas Creek nr Montezuma, NM	84	65.6	36	1.82	3.09	4.5	0.042	297	1.4
Gila River at Bird Area	2600	351	178	2	4.5				
Gila River blw Blue Creek nr Virden, NM	3202	303.2	85	3.6	5.3	5.7	0.032	1738	1.2
Hunter Wash	48	46	35	1.3	1.9				
Hwy 44, MP121	2.5	10.58	23	0.5	0.8				
Hwy 44, MP123	1.5	7.55	20	0.4	0.6				
Hwy. 12 outside Reserve	37.17	47.5	69	0.7	1.7				
Hwy. 32 below Apache Cr. (Largo Canyon)	23.5	34.79	22.5	1.5	2				
Jct. 209 and 180	0.8	3.9	10	0.4	0.8				
Jemez River ab Rio Guadalupe, NM	220	59.6	35	1.7	2.9				
Jemez River nr Jemez, NM	470	190	72.86	2.61	4.8	5.8	0.041	1100	1.6
Jewett Gap	2	5.78	8	0.7	1.3				
La Jara Arroyo, NM	96	44.45	52	0.9	1.2				
Mail Hollow nr Luna, NM	4.2	11.8	15.8	0.75	1.63	3.0	0.042	35	1.5
Middle Fork Ponil Creek	65	36.85	26	1.4	2.2				
Mimbres River at Mimbres, NM	216	94.5	92	1.03	2.23	6.2	0.022	582	1.5
Morgan Creek	17.56	10.76	16	0.7	1.1				
Mt. Taylor #1	1.2	7	11	0.4	1				
N Fork Palomas	16.1	9.67	28	0.3	0.9				
Pecos River at Pecos, NM	189	78.6	38	2.1	2.8	4.3	0.053	340	1.3
Pine Canyon - Cibola	5.5	10.2	13.5	0.8	1.4				
Ponil Creek above Gage	168	40.1	23	1.7	2.6				
Ponil Creek nr Cimarron, NM	171	44.7	32.34	1.38	2.4	7.1	0.009	316	1.7
Rayado Creek ab. Miami Lane	160	66	24.5	2.7	3.9				
Red River nr Questa, NM	113	48.1	35.1	1.37	2.4	4.2	0.037	202	1.6
Rio Bonito	80.29	20.6	19	1.1	1.5				
Rio Brazos @ County Rd. 573	132.34	99.8	54	1.8	3.2				
Rio Grande blw Taos Jct. Bridge, NM	9730	413.8	116.7	3.55	5.88	7.0	0.013	2900	1.8
Rio Grande del Rancho nr Talpa, NM	83	44.7	23.6	1.89	2.57	2.7	0.033	120	1.7
Rio Hondo nr Valdez, NM	36	37.87	30.56	1.24	1.88	4.0	0.059	152	1.8
Rio Lucero nr Arroyo Seco, NM	16.6	30.5	31.15	0.98	1.65	3.7	0.044	113	1.7
Rio Mora nr Terrero, NM	53.2	48.4	33	1.5	1.8	3.8	0.055	182	1.4
Rio Ojo Caliente at La Madera, NM	419	128	57	2.25	3.9	5.5	0.040	700	1.4
Rio Pueblo nr Penasco, NM	101	71.9	41.35	1.74	3.1	5.7	0.042	411	1.6
Rio Ruidoso at Hollywood, NM	120	37.3	26.7	1.4	2.46	4.1	0.036	152	1.4
Rio Santa Barbara nr Penasco, NM	38	52	31.65	1.65	2.45	4.7	0.073	245	1.8
Saliz Cr. Blw Wet and Dry Leggett	17	23	22	1.1	2				
San Antonio Creek	46.6	42.01	27	1.6	2.1				
San Francisco nr Reserve (gage site)	350	77.3	54	1.4	3.6				
San Francisco River above Luna, NM	30	31.7	13.5	2.3	3.8				

San Francisco River nr Glenwood, NM	1653	227.8	110.8	2.1	4.3	6.1	0.017	1400	1.4
Sandy Wash at Catron Billboard	3.3	7.8	18	0.4	0.6				
Santa Fe above Cochiti Reservoir, NM	200	72.35	29	2.5	3.7	8.1	0.028	585	1.5
Sixteen Springs Canyon	19.92	13.9	19	0.7	1.7				
Tajique Campground	17.27	14.55	23	0.6	1.2				
Trib to Copperas Canyon #1	1.2	5.75	9	0.6	1.1				
Trib to Largo Cr.-Apache NF	3.6	7	12.3	0.6	1.1				
Trib to Trout Creek on hwy 15	2.6	8.5	15.5	0.5	0.8				
Tularosa River ab Aragon, NM	94	20.4	19.8	1.03	1.9	2.4	0.041	48	1.6
Tularosa River below Canyon	426	48.3	36.5	1.3	2.3				
V1 Canyon	6.81	15.04	16	0.9	1.3				
Water Canyon	16.4	10.8	23	0.5	1.2				
White Oaks Draw	25.58	42.29	34	1.2	2.1				
Whitewater Creek at Catwalk	35	35.7	38	0.9	1.1				
SA Canyon	4	27.6	21	1.3	2.1				
Santa Fe River nr Santa Fe, NM	18.2	14.29	14.85	0.96	1.36	2.3	0.076	32.5	1.5

Appendix A3. Delineative Criteria and Classifications.

Table A3. Delineative Criteria and Classifications.

SITE NAME	W/D	ER	Slope	Sinuosity	Bed Material	d15	d50	d84	Channel Type	RI (yrs)
GAGED SITES										
Bluewater Creek ab Bluewater Dam, NM	64.27	2.19	0.0009	1.4	Fine Sand	0.06	0.16	32	C5	1.7
Copperas Canyon nr Pinos Altos, NM	23.58	1.41	0.0257	1.1	Med Gravel	0.1	11	70	B4	1
Duck Creek nr Cliff, NM	17.65	1.23	0.008	1.1	sand	0.06	0.16	4	F5	1.1
Eagle Creek Below South Fork nr Alto, NM	21.48	1.9	0.022	1.1	Coarse Gravel	0.5	27	112	B4	1.4
Embudo Creek at Dixon, NM	19	2.7	0.01	1.2	Gravel	0.1	42	130	C4	1.8
Gallinas Creek nr Montezuma, NM	19.7	1.93	0.008	1.2	Gravel	0.1	36	88	B4c	1.4
Gila River blw Blue Creek nr Virden, NM	23.8	3.9	0.003	1.1	Med Sand	0.38	0.45	11	C5	1.2
Jemez River nr Jemez, NM	27.9	2.32	0.0075	1.2	Coarse Gravel	0.1	28	120	C4	1.6
Mail Hollow nr Luna, NM	21.16	2.9	0.0104	1.3	Coarse Sand	0.1	2	23	C5	1.5
Mimbres River at Mimbres, NM	89.57	2.07	0.009	1.1	V Coarse Gravel	13	43	76	C4	1.5
Pecos River at Pecos, NM	18.4	1.6	0.009	1.1	Cobble				B3c	1.3
Ponil Creek nr Cimarron, NM	23.4	2.22	0.0011	1.1	Gravel	0.1	16	85	C4	1.7
Red River nr Questa, NM	25.61	2.16	0.0072	1.4	Gravel	0.1	29	78	C4	1.6
Rio Grande blw Taos Jct. Bridge, NM	32.91	1.65	0.0007	1	Sand				F5	1.8
Rio Grande del Rancho nr Talpa, NM	12.46	2.58	0.0016	1.1	Gravel	0.1	24	105	C4	1.7
Rio Hondo nr Valdez, NM	24.66	1.75	0.0194	1.1	Large Gravel	15	53	150	B4	1.8
Rio Lucero nr Arroyo Seco, NM	31.81	1.55	0.0126	1.1	Coarse Gravel	6	37	95	B4	1.7
Rio Mora nr Terrero, NM	22.5	1.2	0.012	1.2	Gravel	28	70	130	B4c	1.4
Rio Ojo Caliente at La Madera, NM	25.4	1.9	0.0075	1.1	Fine Gravel				C4	1.4
Rio Pueblo nr Penasco, NM	23.78	5.22	0.0129	1.1	Small cobble	22	75	140	C3	1.6
Rio Ruidoso at Hollywood, NM	19.11	1.63	0.0066	1.1	Coarse Gravel	0.1	19	57	B4c	1.4
Rio Santa Barbara nr Penasco, NM	19.2	2.3	0.0276	1.1	Small cobble	9	77	220	B3	1.8
San Francisco River nr Glenwood, NM	53.9	1.9	0.002	1.3	Med Sand	0.10	0.32	8	C5	1.4
Santa Fe above Cochiti Reservoir, NM	11.6	1.9	0.0068	1.3	Gravel	0	20	0	C4	1.5
Santa Fe River nr Santa Fe, NM	15.43	1.52	0.015	1.2	Gravel	15	32	110	B4c	1.5
Tularosa River ab Aragon, NM	19.22	2.55	0.0043	1.1	Sand	0.06	0.07	24	C5	1.6
UNGAGED SITES										
Apache #2-East of Picture Tank	38.9	1.7	0.005	1.1	gravel	0.1	22	70	B4c	
Apache Creek	64.6	1.7	0.008	1.2	Sand	0.1	1	8.5	B5c	
Apache Creek trib (Red Steer Canyon)	27.4	1.6	0.024	1.2	Gravel	0.02	5	70	B4	
Bluewater Creek above FS campground	14.3	2.6	0.007	1.2	sand	0.1	8	30	C5	
Bluewater Creek trib.	12.6	2.8	0.021	1.1	Gravel	0.1	15	40	C4b	
Cieniguilla Creek at Gage	12.8	5.2	0.004	1.8	Silt	0.1	2.5	50	E6	
Cieniquilla Creek blw Angel fire	10.7	3.9	0.004	1.6	sand	0.1	0.5	24	E5	
Cimarron River blw Miami Lane	14.9	3	0.002	1.2	sand				C5	
Coal Mine Campground	36.6	1.8	0.038	1.2	Sand	0.1	0.2	15	B5	
Cottonwood Gulch	32.2	1.9	0.025	1.1	Cobble	0.1	70	200	B3	
Crownpoint#1 below Hwy.9 Bridge	27.6	2.5	0.002	1.2	Silt	0.01	0.01	0.01	C6	
Dry Canyon	37.8	1.7	0.029	1.2	Gravel	0.1	15	50	F4b	
E Red Canyon	19.8	2.9	0.018	1.1	Gravel	0.5	7	28	C4	
Eagle Creek Trib #1	11.3	2.6	0.127	1.1	Gravel	0.01	30	120	A4a+	
East Fork Gila river at Grapevine Campground	34.2	1.6	0.005	1.2	Gravel	0.1	18	45	F4	
FS 547 Road - Cibola	17.8	1.9	0.031	1.3	Sand	0.01	0.1	15	B5	
Gila River at Bird Area	90.2	2	0.004	1.2	Gravel	0.1	5	25	C4	
Hunter Wash	26.8	1.6	0.005	1.1	Silt	0.01	0.02	2	B6c	
Hwy 44, MP121	50	1.2	0.009	1.2	sand	0.01	0.01	0.01	B5c	
Hwy 44, MP123	53	1.4	0.009	1.1	sand	0.01	0.01	0.01	B5c	
Hwy. 12 outside Reserve	100.2	1.5	0.015	1.2	Gravel	0.02	8.00	50	F4	
Hwy. 32 below Apache Cr. (Largo Canyon)	14.6	1.7	0.013	1.1	gravel	0.2	12	40	B4c	
Jct. 209 and 180	25.8	1.6	0.029	1.1	Gravel	0.01	20	60	B4	
Jemez River ab Rio Guadalupe, NM	20.5	4.3	0.005	1.2	Gravel	0.01	25	90	C4	
Jewett Gap	11.1	3.4	0.037	1.1	Cobble	0.01	2	30	E3b	
La Jara Arroyo, NM	60.8	1.9	0.009	1.1	sand	0.01	0.01	0.01	B5c	
Middle Fork Ponil Creek	18.3	2.7	0.013	1.3	GRAVEL	0.6	23	100	C4	
Morgan Creek	23.8	1.9	0.011	1.1	Gravel	0.2	20	154	B4c	
Mt. Taylor #1	26.3	2.7	0.086	1.1	gravel	0.1	9	150	C4a	
N Fork Palomas	81.1	2.7	0.014	1.1	Fine gravel	0.4	3	28	C4	
Pine Canyon - Cibola	17.9	3	0.005	1.2	Gravel	0.1	20	90	C4	
Ponil Creek above Gage	13.2	2.3	0.003	1.2	Fine gravel	0.1	1.5	55	C5	
Rayado Creek ab. Miami Lane	9.1	2.7	0.006	1.3	gravel	0.1	18	55	C4	
Rio Bonito	19.6	2.3	0.006	1.2	Gravel	0.01	11	32	C4	
Rio Brazos @ County Rd. 573	29.2	3.7	0.015	1.1	cobble	0.00	100	300	C3	
SA Canyon	16	2.6	0.049	1.2	gravel	0.4	25	100	C4b	

Saliz Cr. Blw Wet and Dry Leggett	20.9	2	0.016	1.2	gravel			B4c
San Antonio Creek	17.4	2	0.014	1.1	Cobble	0.1	70	130	C3
San Francisco nr Reserve (gage site)	37.7	2.6	0.005	1.2	Sand	0.01	0.3	55	C5
San Francisco River above Luna, NM	5.8	6.7	0.012	1.1	Cobble		125		C3
Sandy Wash at Catron Billboard	41.3	2.1	0.015	1.2	Sand	0.20	0.3	2	C5
Sixteen Springs Canyon	26	1.5	0.015	1.1	Gravel	0.01	40	80	B4c
Tajique Campground	36.4	1.6	0.006	1.1	Small Gravel	0.01	5	109	C4
Trib to Copperas Canyon #1	14.1	2.4	0.038	1.2	Gravel	0.01	3	30	C4b
Trib to Largo Cr.-Apache NF	21.6	1.8	0.01	1.1	sand	0.2	0.3	2	B5c
Trib to Trout Creek on hwy 15	28.2	1.2	0.01	1.1	Gravel	0.3	20	100	F4
Tularosa River below Canyon	27.6	1.7	0.004	1.2	Sand	0.1	0.1	33	B5c
V1 Canyon	17	2.3	0.024	1.1	gravel	0.3	20	99	C5b
Water Canyon	49	1.6	0.025	1.1	gravel	0.02	7	80	B4
White Oaks Draw	27.3	3.2	0.022	1.1	gravel	0.2	20	80	C4b
Whitewater Creek at Catwalk	40.5	1.1	0.02	1.1	Gravel	4	30	93	F4

Appendix B: Proposed New Mexico Sub-Regions

Appendix B1

Cimarron/Upper Pecos Region

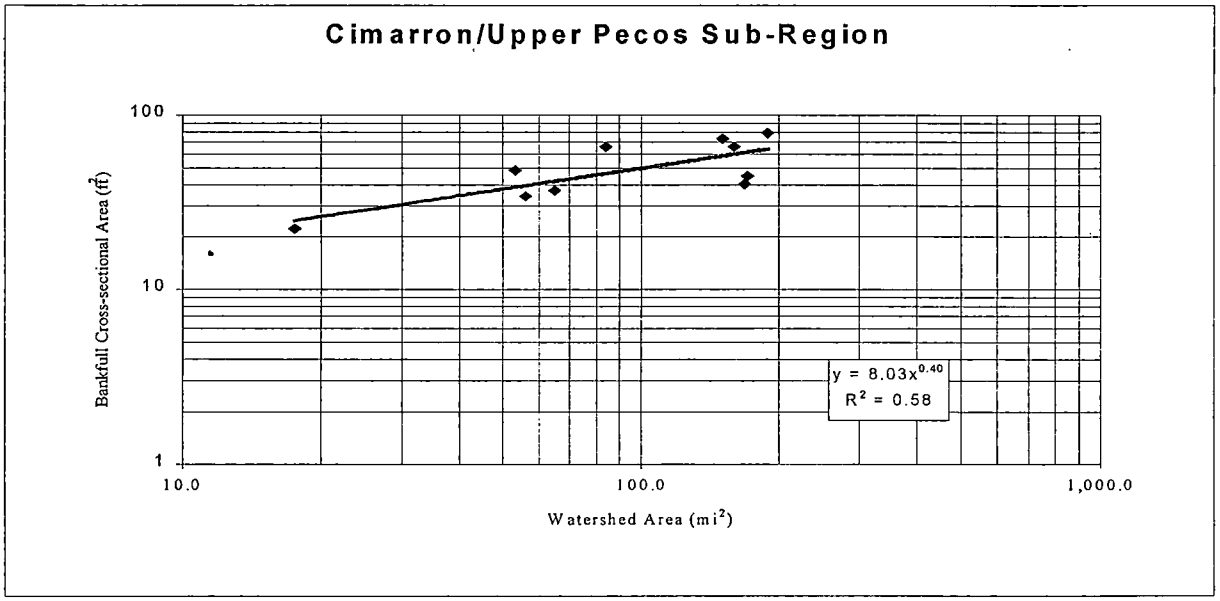
HUCs: 11080001, 11080002, 11080003, 11080004, 11080005, 13060001, 13060002
Number of study sites: 10
Number of gaged sites: 4
Mean recurrence interval: 1.5 years

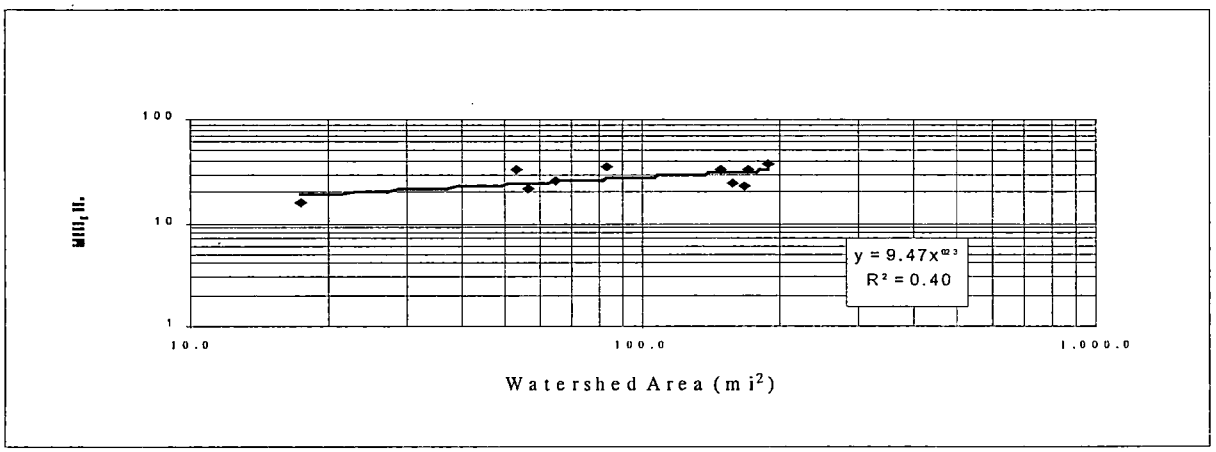
This region includes the eastern and southern watersheds of the Sangre de Cristo Mountains. The watersheds are characterized by mountainous terrain in the upper reaches flattening out onto the broad plains of eastern New Mexico. The region is represented by 7 hydrologic units and included 10 study sites .The climate is moderately wet in the upper ends of the watersheds with a high elevation snow pack. "Rain on snow" events can contribute greatly to high stream flows. Study sites were located on perennial streams and bankfull stage was relatively easy to identify in the field. Sites in the Cimarron watershed were low gradient alluvial systems with easily identified floodplain features. Sites in the Gallinas, Pecos, and Mora basins were steeper, narrower channels with less obvious bankfull features. In general the data points were consistent with the regional curve. Analyses of the individual study sites suggests that Ponil Creek within the Cimarron watershed may produce somewhat smaller bankfull geometries and that the Gallinas, Pecos, and Mora watersheds in the southern end of the region may produce slightly larger bankfull values. Four stream gage sites were included in the study sites. Recurrence interval values ranged from 1.3 to 1.7 years with a mean of 1.5 years.

Table B1. Data for Upper Pecos Sub-Region.

Site Name	HUC	Watershed	WS Area (mi2)	XS Area (ft2)	Width (ft)	Mean Depth (ft)	Channel Type	RI (yrs)	Q (cfs)
Cieniquilla Creek blw Angelfire	11080002	Cimarron	17.5	22.4	15.5	1.4	E5		
Rio Mora nr Terrero, NM	13060001	Upper Pecos	53.2	48.4	33.0	1.5	B4c	1.4	182
Cieniguilla Creek at Gage	11080002	Cimarron	56.0	34.4	21.0	1.6	E6		
Middle Fork Ponil Creek	11080002	Cimarron	65.0	36.9	26.0	1.4	C4		
Gallinas Creek nr Montezuma, NM	13060001	Upper Pecos	84.0	65.6	36.0	1.8	B4c	1.4	297
Cimarron River blw Miami Lane	11080002	Cimarron	150.7	73.0	33.0	2.2	C5		
Rayado Creek ab. Miami Lane	11080002	Cimarron	160.0	66.0	24.5	2.7	C4		
Ponil Creek above Gage	11080002	Cimarron	168.0	40.1	23.0	1.7	C5		
Ponil Creek nr Cimarron, NM	11080002	Cimarron	171.0	44.7	32.3	1.4	C4	1.7	316
Pecos River at Pecos, NM	13060001	Upper Pecos	189.0	78.6	38.0	2.1	B3c	1.3	340

Figure B1. Data for Cimarron/Upper Pecos Sub-Region.





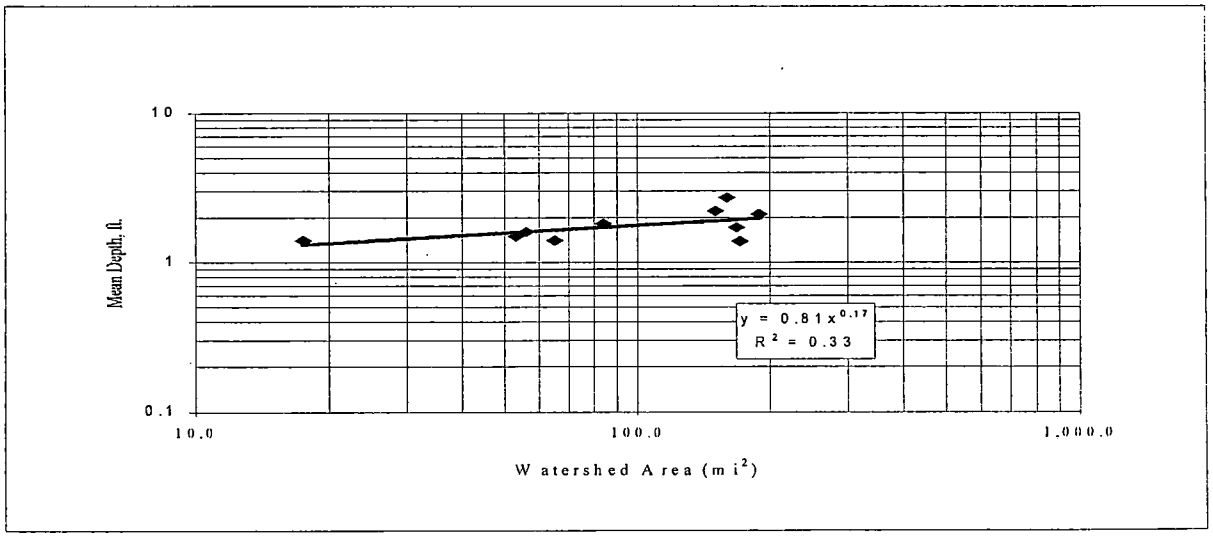
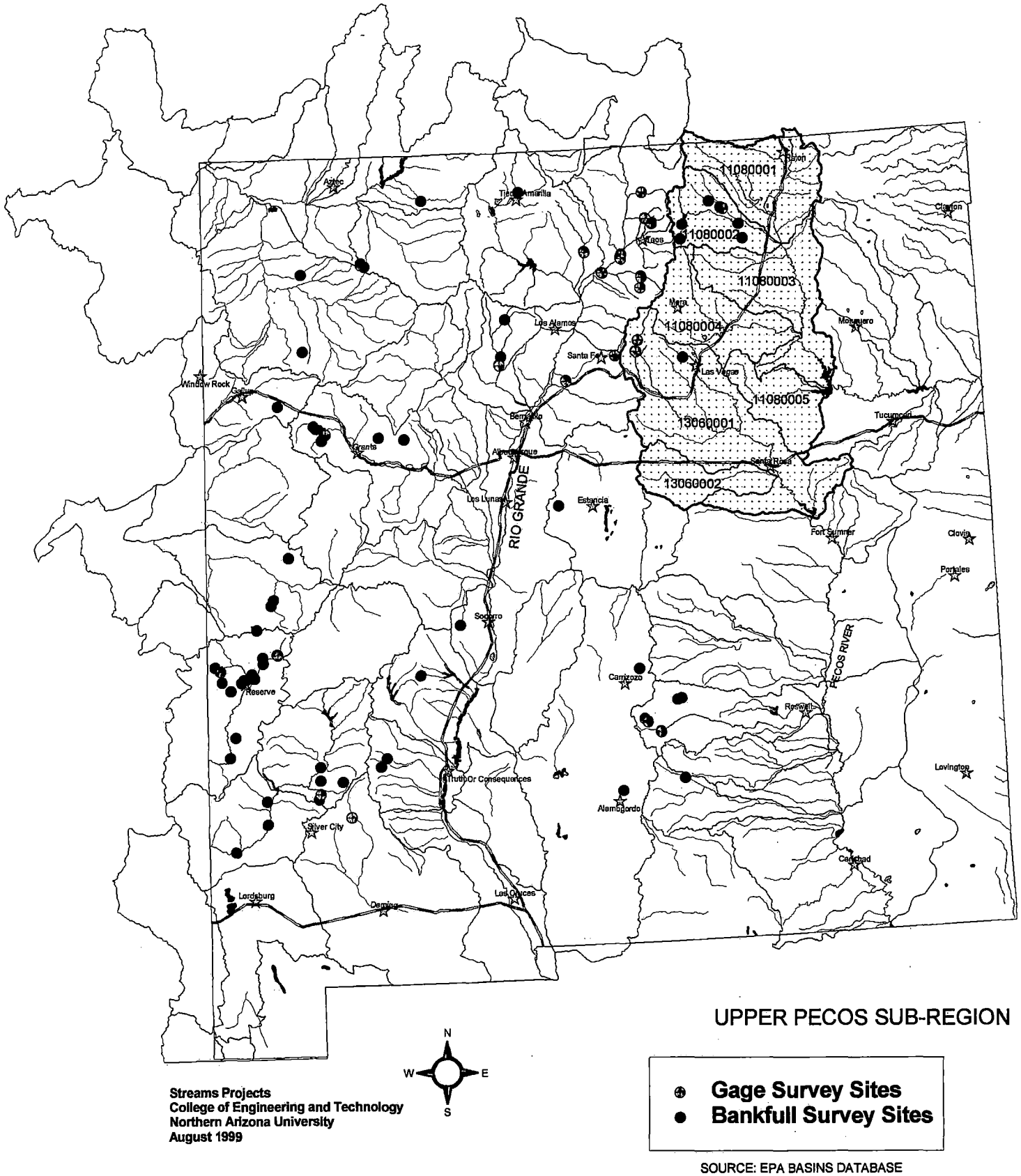


Figure B2. Map of Upper Pecos Sub-Region



Appendix B2

Chama/Taos/Jemez Sub-Region

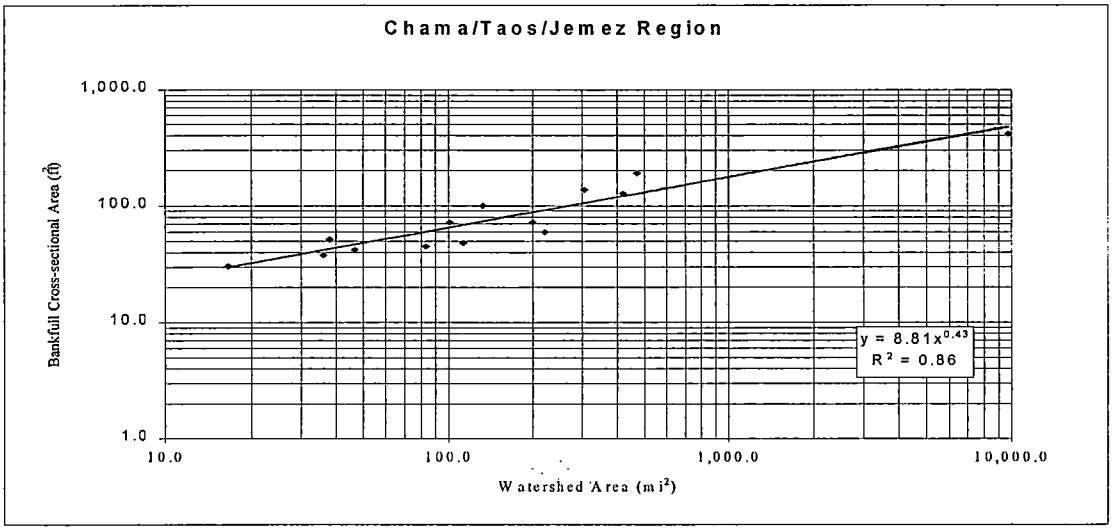
HUCs: 13010005, 13020101, 13020102, 13020201, 13020202, 13020203, 13020204
Number of study sites: 14
Number of gaged sites: 11
Mean recurrence interval: 1.7 years

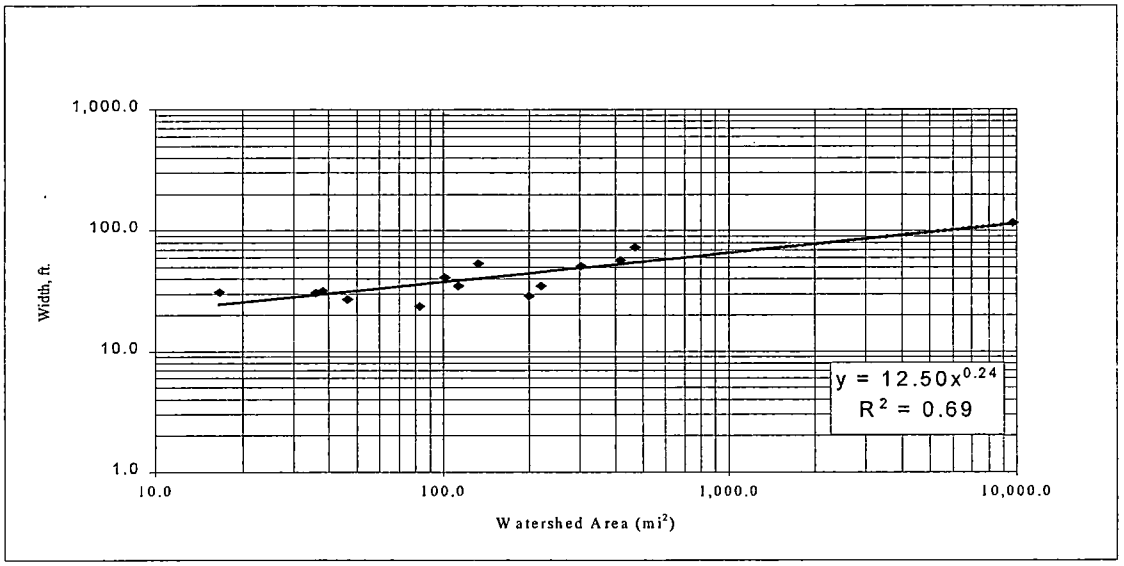
This region includes the watersheds of the north central region of the state. The region is dominated by high elevations and streams that drain the San Juan, San Pedro, Jemez, and Sangre de Cristo Mountains and is bisected by the Rio Grande River. The region is divided into 5 Hydrologic Units (USGS HUCs), contains 14 study sites and has abundant perennial streams. The climate is relatively wet with considerable high elevation snow pack. "Rain on snow" events can produce significant high stream flows. Study sites were all perennial and indicators of bankfull stage were easily identified. These indicators were generally alluvial features representing the floodplain elevation. The cross-sectional area data lies consistently above the regional trendline. These watersheds can be expected to produce somewhat larger bankfull channel geometries than for the state on average. This is especially true for the streams that drain the western slopes of the Sangre de Cristo Mountains. Recurrence intervals ranged from 1.4 to 1.8 years with an average of 1.7 years.

Table B2. Data for Chama/Taos/Jemez Sub-Region.

Site Name	HUC	Watershed	WS Area (mi2)	XS Area (ft2)	Width (ft)	Mean Depth (ft)	Channel Type	RI (yrs)	Q (cfs)
Rio Lucero nr Arroyo Seco, NM	13020101	Upper Rio Grande	16.6	30.5	31.2	1.0	B4	1.7	113
Rio Hondo nr Valdez, NM	13020101	Upper Rio Grande	36.0	37.9	30.6	1.2	B4	1.8	152
Rio Santa Barbara nr Penasco, NM	13020101	Upper Rio Grande	38.0	52.0	31.7	1.7	B3	1.8	245
San Antonio Creek	13020202	Jemez	46.6	42.0	27.0	1.6	C3		
Rio Grande del Rancho nr Talpa, NM	13020101	Upper Rio Grande	83.0	44.7	23.6	1.9	C4	1.7	120
Rio Pueblo nr Penasco, NM	13020101	Upper Rio Grande	101.0	71.9	41.4	1.7	C3	1.6	411
Red River nr Questa, NM	13020101	Upper Rio Grande	113.0	48.1	35.1	1.4	C4	1.6	202
Rio Brazos @ County Rd. 573	13020102	Chama	132.3	99.8	54.0	1.8	C3		
Santa Fe above Cochiti Reservoir, NM	13020201	Upper Rio Grande	200.0	72.4	29.0	2.5	C4		
Jemez River ab Rio Guadalupe, NM	13020202	Jemez	220.0	59.6	35.0	1.7	C4		
Embudo Creek at Dixon, NM	13020101	Upper Rio Grande	305.0	137.7	51.1	2.7	C4	1.8	976
Rio Ojo Caliente at La Madera, NM	13020102	Chama	419.0	128.0	57.0	2.3	C4	1.4	700
Jemez River nr Jemez, NM	13020202	Jemez	470.0	190.0	72.9	2.6	C4	1.6	1100
Rio Grande blw Taos Jct. Bridge, NM	13020101	Upper Rio Grande	9730.0	413.8	116.7	3.6	F5	1.8	2900

Figure B3. Data for Chama/Taos/Jemez Sub-Region.





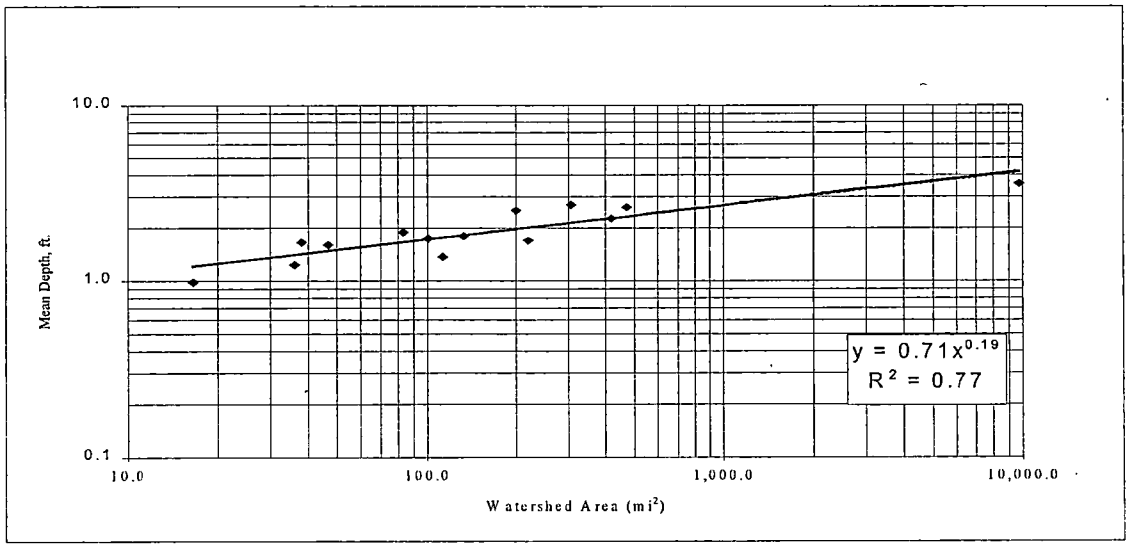
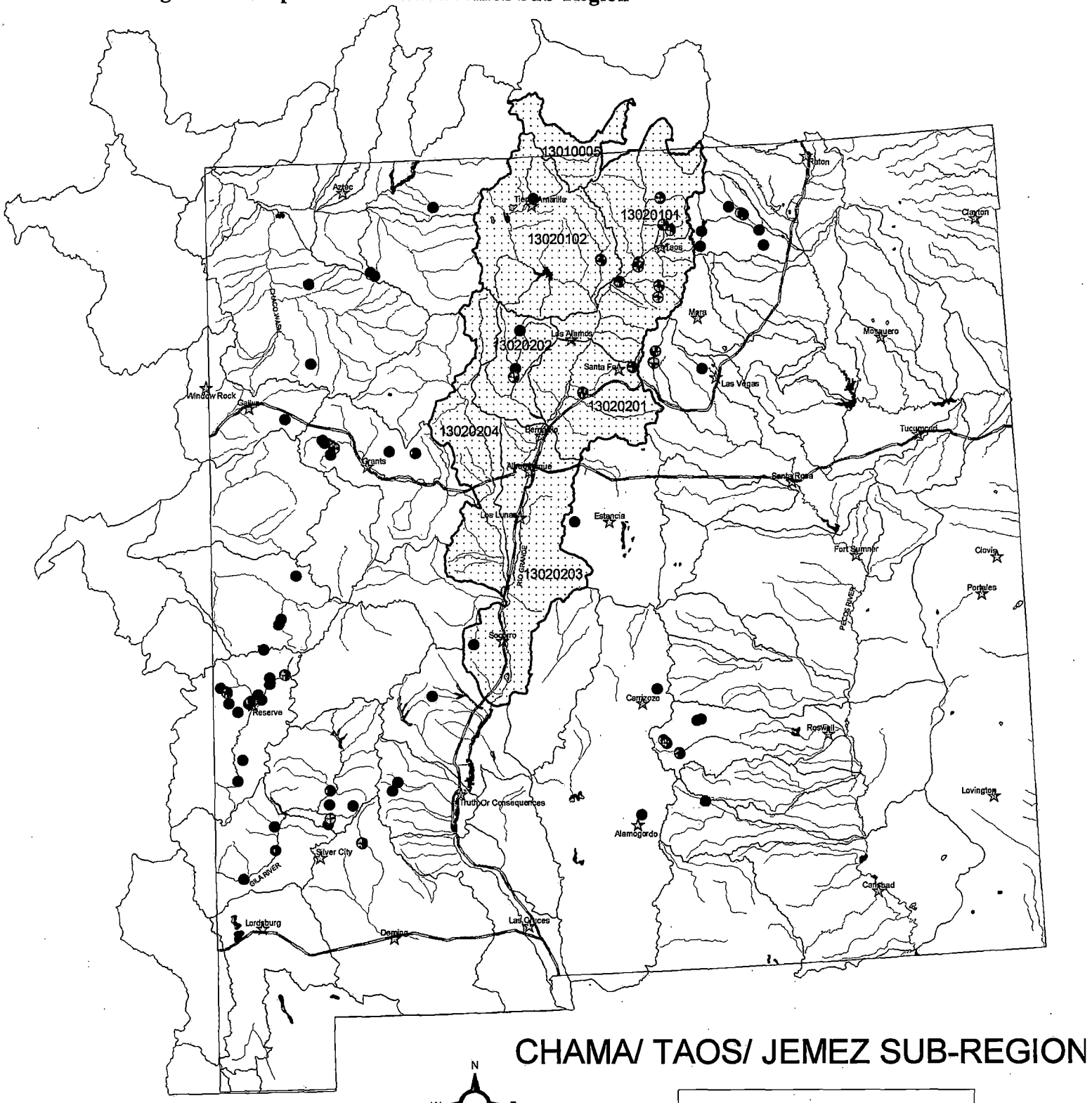


Figure B4. Map of Chama/Taos/Jemez Sub-Region



CHAMA/ TAOS/ JEMEZ SUB-REGION

N
W E
S

Streams Projects
College of Engineering and Technology
Northern Arizona University
August 1999

- **Gage Survey Sites**
- **Bankfull Survey Sites**

SOURCE: EPA BASINS DATABASE

Appendix B3

Zuni Mountains Sub-Region

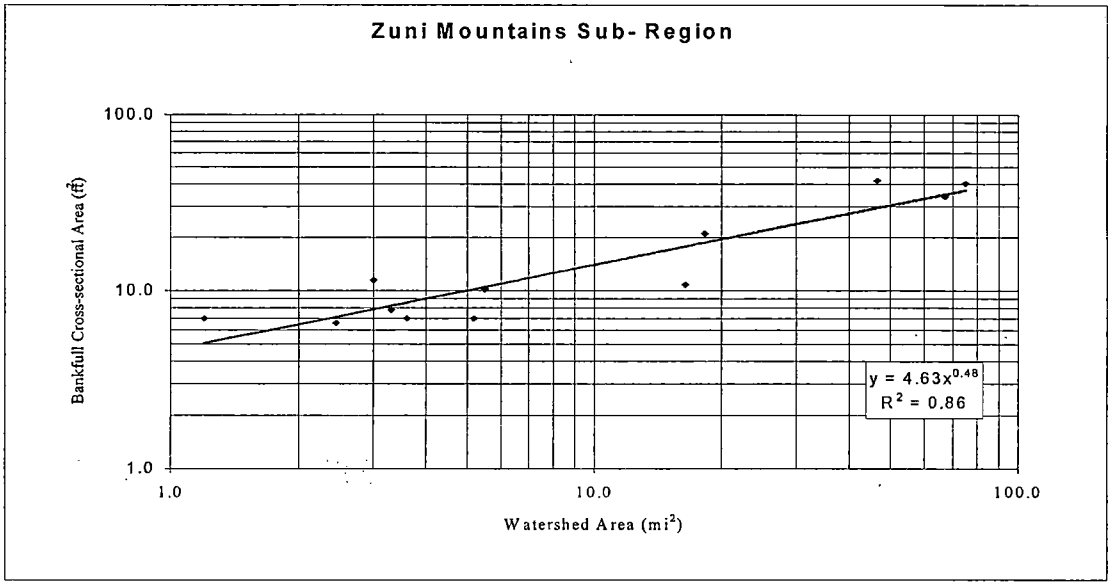
HUCs: 13020206, 13020207, 13020208, 13020209, 15020001, 15020002, 15020003, 15020004, 15020006
Number of study sites: 12
Number of gaged sites: 1
Mean Recurrence interval: 1.7 years

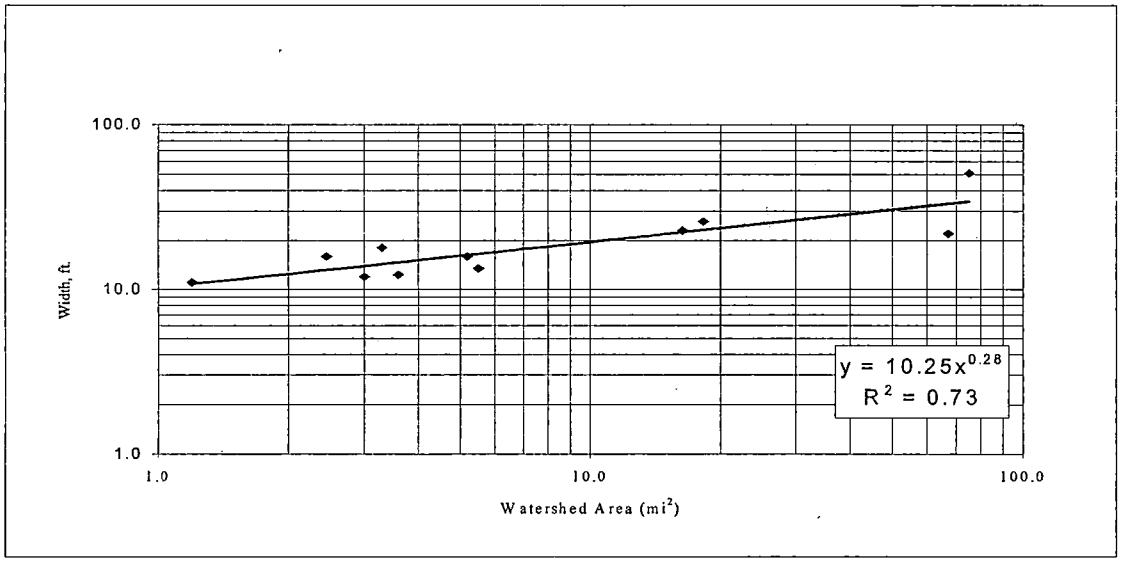
This region lies in western portion of the state straddling the Continental Divide and contributing flow to the Rio Grande, Gila, and Little Colorado Rivers. The Zuni Mountains dominate the central portion of the region and are the primary source of streamflow. The region is divided into 9 Hydrologic Units and contains 12 study sites, although only 1 is located at a gaging station. The region is semi-arid with a mixture of perennial, intermittent, and ephemeral streams. Each of these flow regimes were represented in the study sites. Alluvial bankfull indicators were often small and disconnected especially at intermittent and ephemeral channels. Due to small or non-existent base flows, vegetation was an inconsistent indicator. Data points tended to fall at or below the regional trendline suggesting that smaller bankfull geometries can be expected. Bankfull discharge at the gaging station on Bluewater Creek had a recurrence interval of 1.7 years. That single data point is not sufficient to predict the expected recurrence interval for the region.

Table B3. Data for Zuni Mountains Sub-Region.

Site Name	HUC	Watershed	WS Area (mi2)	XS Area (ft2)	Width	Mean Depth (ft)	Channel Type	RI (yrs)	Q (cfs)
FS 547 Road - Cibola	15020006	Little Colorado	0.3	2.4	6.5	0.4	B5		
Mt. Taylor #1	13020207	Middle Rio Grande	1.2	7.0	11.0	0.4	C4a		
Apache #2-East of Picture Tank	15020003	Little Colorado	2.5	6.6	16.0	0.4	B4c		
Bluewater Creek trib.	13020207	Middle Rio Grande	3.0	11.4	12.0	1.0	C4b		
Sandy Wash at Catron Billboard	15020003	Little Colorado	3.3	7.8	18.0	0.4	C5		
Trib to Largo Cr.-Apache NF	15020003	Little Colorado	3.6	7.0	12.3	0.6	B5a		
Coal Mine Campground	13020207	Middle Rio Grande	5.2	7.0	16.0	0.4	B5		
Pine Canyon - Cibola	13020207	Upper Gila	5.5	10.2	13.5	0.8	C4		
Water Canyon	13020209	Middle Rio Grande	16.4	10.8	23.0	0.5	B4		
Cottonwood Gulch	13020207	Middle Rio Grande	18.3	21.0	26.0	0.8	B3		
Bluewater Creek above FS campground	13020207	Middle Rio Grande	67.3	34.0	22.0	1.5	C5		
Bluewater Creek ab Bluewater Dam, NM	13020207	Middle Rio Grande	75.0	40.3	50.9	0.8	C5	1.7	129

Figure B5. Data for Zuni Mountains Sub-Region.





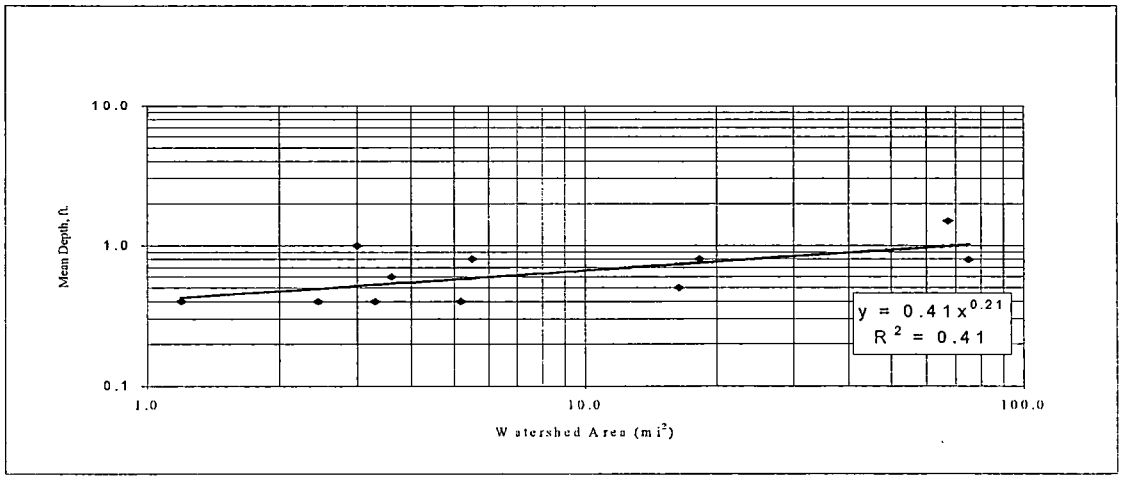
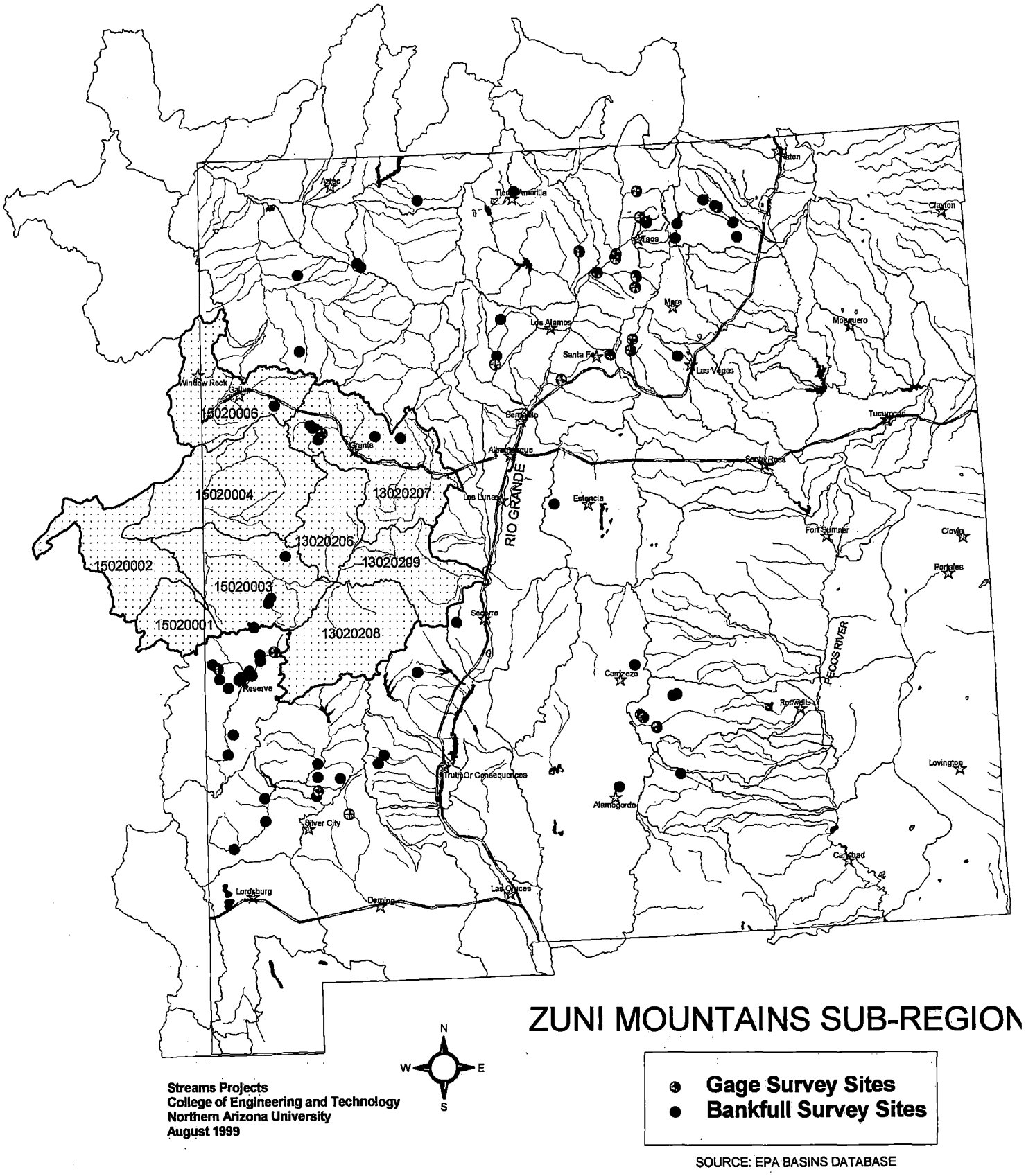


Figure B6. Map of Zuni Mountains Sub-Region



Appendix B4

Chaco/San Juan Sub-Region

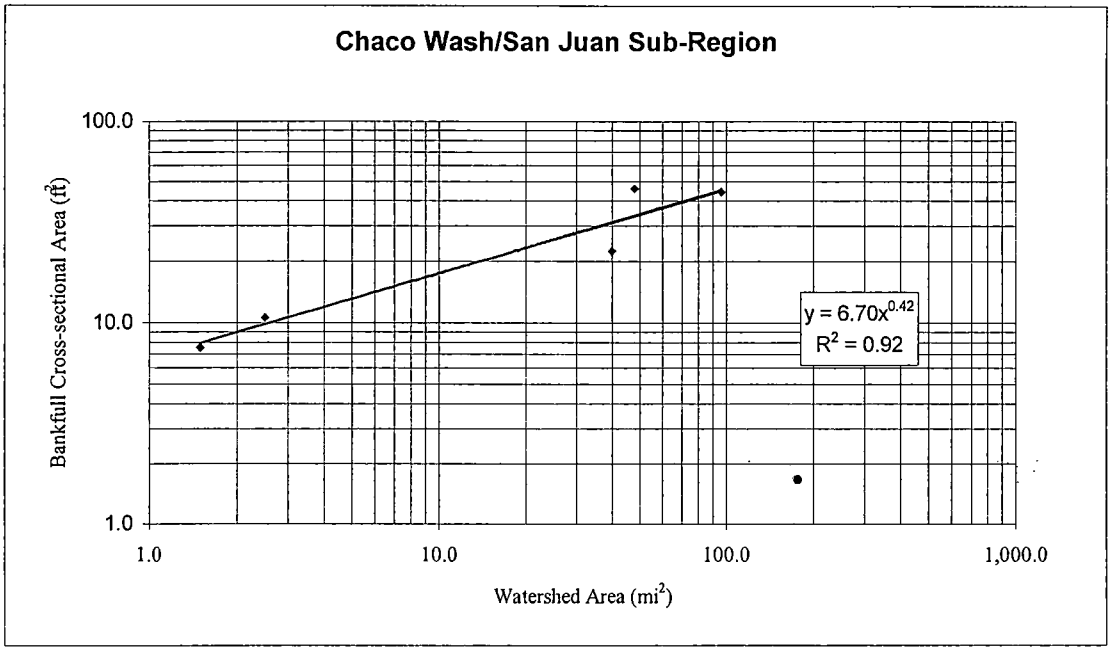
HUCs: 13020205, 14080101, 14080103, 14080104, 14080105, 14080106
Number of study sites: 5
Number of gaged sites: 0
Mean recurrence interval: -

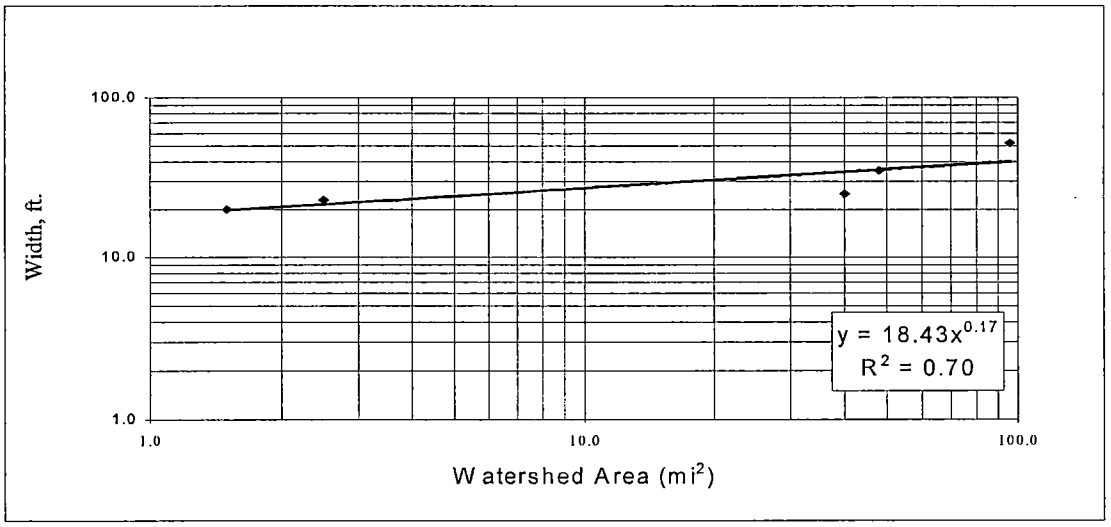
This region lies in the northwestern corner of the state. Along with the south-central region of the state, it represents one of the most arid climates in New Mexico. Perennial streams are uncommon and all study sites were on intermittent or ephemeral channels. The landscape is low relief and stream gradients are also low. Stream sediment is high due to highly erosive soils and sparse vegetation. Channel beds are often dominated by sand or silt. Bankfull stage can be extremely difficult to identify. Floodplain features are generally represented by small bars often alternating from one bank to the other. The longitudinal consistency of these features is the best evidence of bankfull stage. There were no appropriate gaging stations available within this region and no recurrence intervals can be calculated. However, work in Arizona and other parts of New Mexico suggest that arid regions often have lower recurrence values than more mountainous regions.

Table B4. Data for Chaco/San Juan Sub-Region.

Site Name	HUC	Watershed	WS Area (mi2)	XS Area (ft2)	Width (ft)	Mean Depth (ft)	Channel Type	RI (yrs)	Q (cfs)
Hwy 44, MP123	14080103	San Juan	1.5	7.6	20.0	0.4	B5c		
Hwy 44, MP121	14080103	San Juan	2.5	10.6	23.0	0.5	B5c		
Crownpoint#1 below Hwy.9 Bridge	14080106	San Juan	40.0	22.7	25.0	0.9	C6		
Hunter Wash	14080106	San Juan	48.0	46.0	35.0	1.3	B6c		
La Jara Arroyo, NM	14080101	San Juan	96.0	44.5	52.0	0.9	B5c		

Figure B7. Data for the Chaco/San Juan Sub-Region.





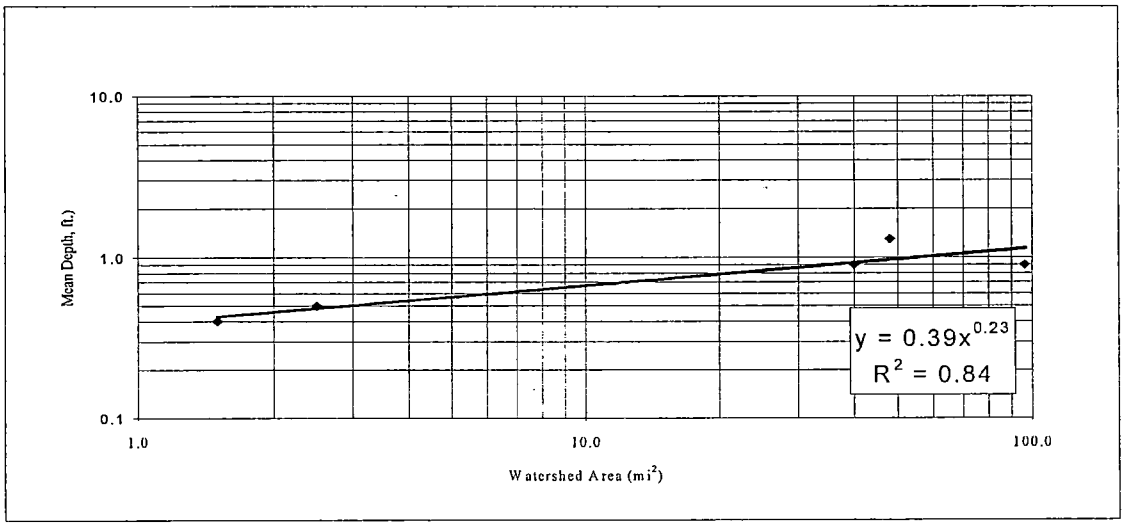
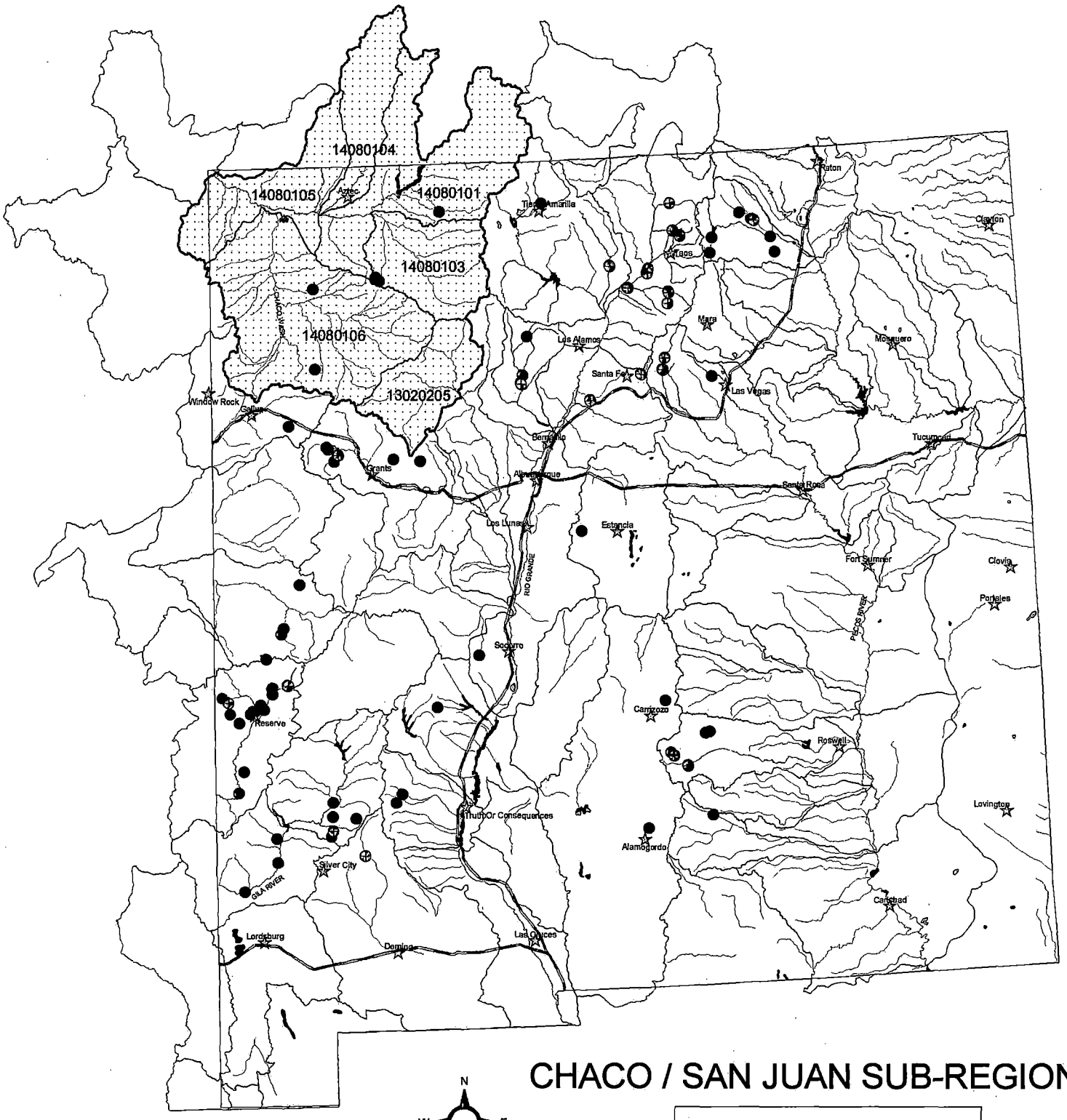


Figure B8. Map of Chaco/San Juan Sub-Region



Appendix B5

Upper Gila Sub-Region

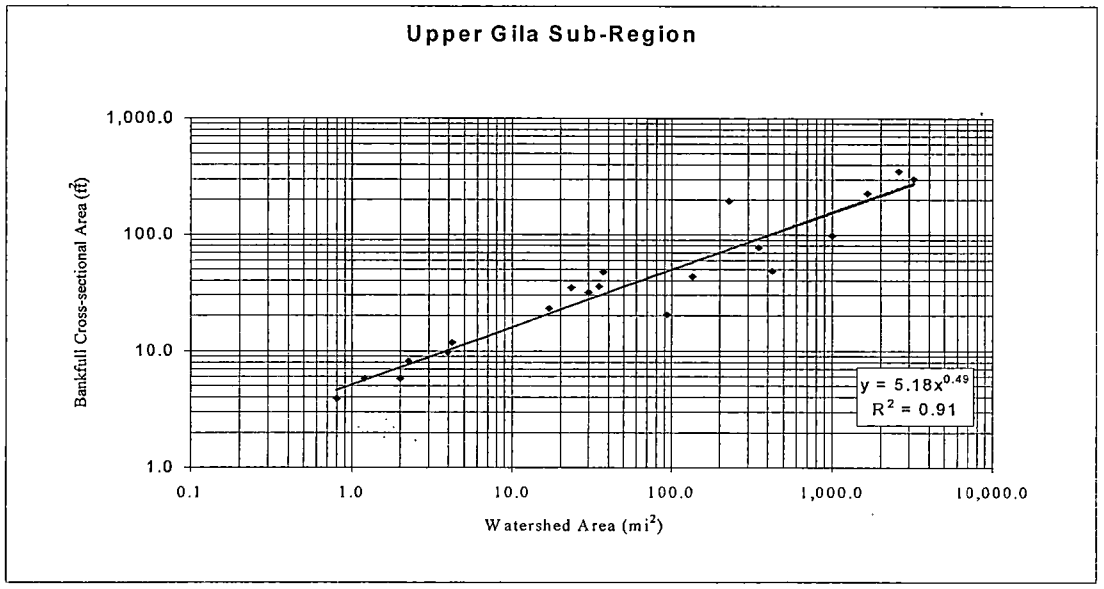
HUCs: 15040001, 15040002, 15040003, 15040004, 15040006
Number of study sites: 21
Number of gaged sites: 6
Mean recurrence interval: 1.3 years

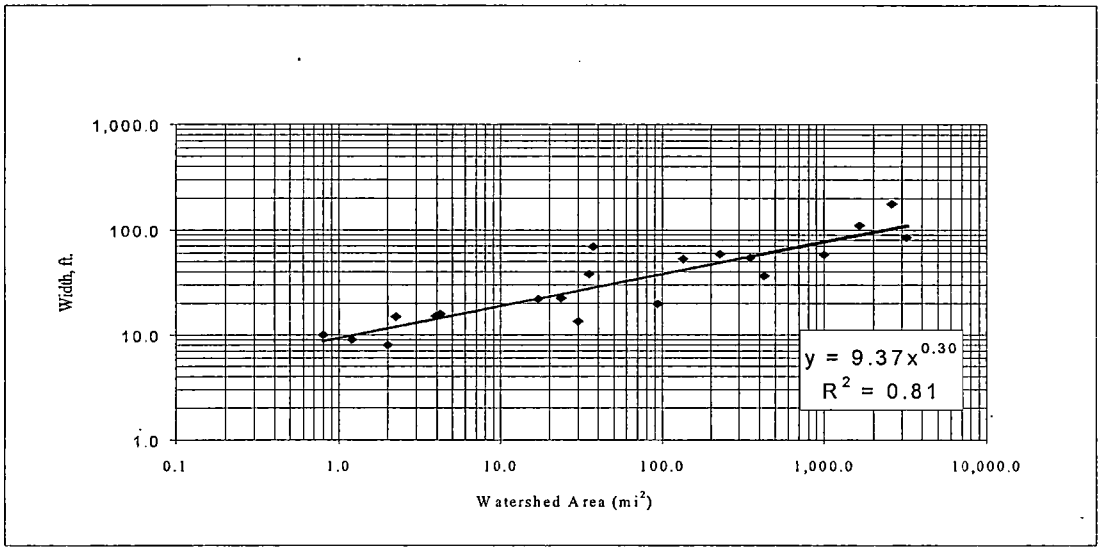
This region consists of the Mogollon Mountains of southwestern New Mexico. The southern latitude creates an arid climate but the high mountains produce a reasonable snow pack. "Rain on snow" events that produce high stream flow are not uncommon. Despite its arid nature, much of the region is forested and the study sites were located on streams at elevations between 4000 ft and 8000 ft. The region is divided into 5 hydrologic units include the San Francisco and upper Gila watersheds. Study sites included perennial, intermittent, and ephemeral streams. Evidence of bankfull stage was often difficult to identify in all flow regimes, potentially due to a shorter flow duration for these events. Recurrence interval values for the gaged sites within this region range from 1.0 to 1.6 years with a mean of 1.3 years, significantly below the state average. The study data is consistent with data generated during the Arizona study for upper Gila sites.
Overall this region's data was consistent with the state data with a couple of outliers. Data for Duck Creek shows channel geometry values greater than others for other sites in the region. Data from Tularosa Creek show smaller channel geometries than for other sites in the region.

Table B5. Data for Upper Gila Sub-Region.

Site Name	HUC	Watershed	WS Area (mi2)	XS Area (ft2)	Width	Mean Depth (ft)	Channel Type	RI (yrs)	Q (cfs)
Jct. 209 and 180	15040004	San Francisco	0.8	3.9	10.0	0.4	B4		
Trib to Copperas Canyon #1	15040001	Upper Gila	1.2	5.8	9.0	0.6	C4b		
Jewett Gap	15040004	Upper Gila	2.0	5.8	8.0	0.7	E3b		
Apache Creek trib (Red Steer Canyon)	15040004	Upper Gila	2.2	8.2	15.0	0.5	B4		
Copperas Canyon nr Pinos Altos, NM	15040001	Upper Gila	4.0	9.8	15.2	0.6	B4	1	50
Mail Hollow nr Luna, NM	15040004	San Francisco	4.2	11.8	15.8	0.8	C5	1.5	35
Saliz Cr. Blw Wet and Dry Leggett	15040004	San Francisco	17.0	23.0	22.0	1.1	B4c		
Hwy. 32 below Apache Cr. (Largo Canyon)	15040004	Upper Gila	23.5	34.8	22.5	1.5	B4c		
San Francisco River above Luna, NM	15040004	San Francisco	30.0	31.7	13.5	2.3	C3		
Whitewater Creek at Catwalk	15040004	San Francisco	35.0	35.7	38.0	0.9	F4		
Hwy. 12 outside Reserve	15040004	San Francisco	37.2	47.5	69.0	0.7	F4		
Tularosa River ab Aragon, NM	15040004	Upper Gila	94.0	20.4	19.8	1.0	C5		
Apache Creek	15040004	Upper Gila	135.0	43.5	53.0	0.8	B5c		
Duck Creek nr Cliff, NM	15040002	Upper Gila	228.0	196.0	58.9	3.3	F5	1.1	1350
San Francisco nr Reserve (gage site)	15040004	San Francisco	350.0	77.3	54.0	1.4	C5		
Tularosa River below Canyon	15040004	Upper Gila	426.0	48.3	36.5	1.3	B5c		
East Fork Gila river at Grapevine Campground	15040001	Upper Gila	1000.0	98.4	58.0	1.7	F4		
San Francisco River nr Glenwood, NM	15040004	San Francisco	1653.0	227.8	110.8	2.1	C5		
Gila River at Bird Area	15040002	Upper Gila	2600.0	351.0	178.0	2.0	C4		
Gila River blw Blue Creek nr Virden, NM	15040002	Upper Gila	3202.0	303.2	85.0	3.6	C5	1.2	1738

Figure B9. Data for the Upper Gila Sub-Region.





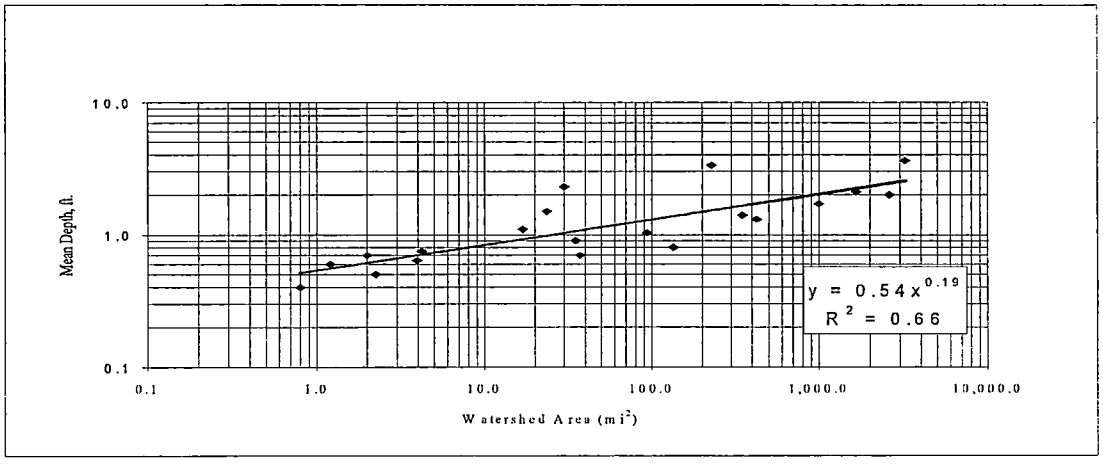
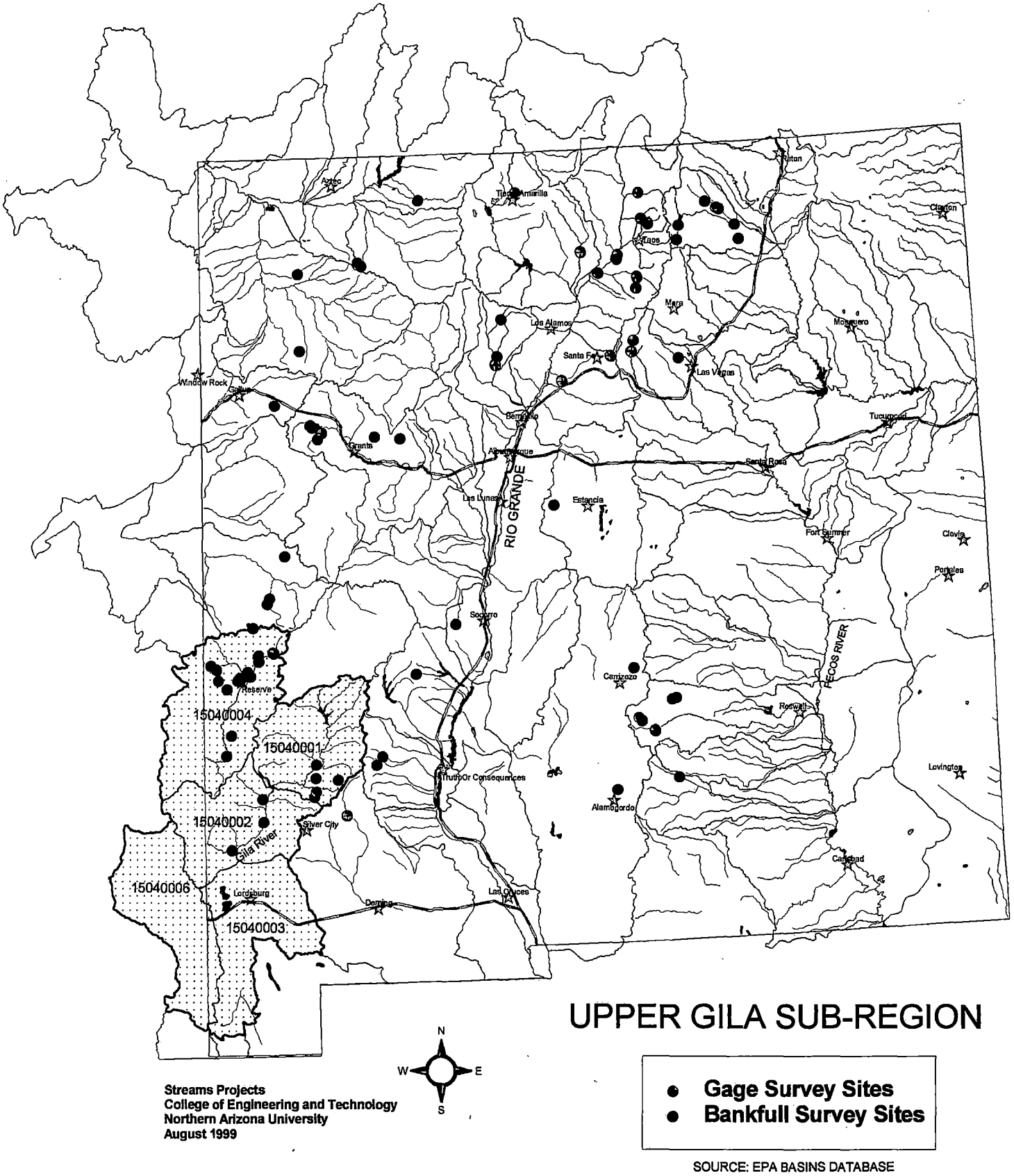


Figure B10. Map of Upper Gila Sub-Region



Appendix B6

Lower Rio Grande Sub-Region

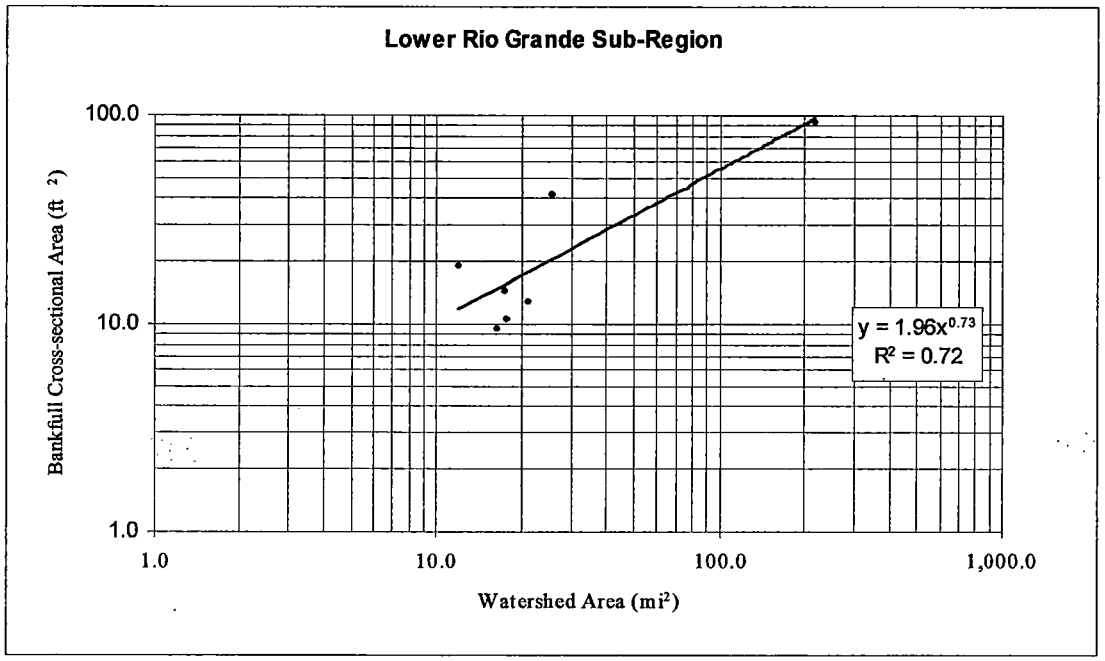
HUCs: 13020203, 13020210, 13020211, 13050003, 13030101, 13030102, 13030103, 13050001, 13050002
Number of study sites: 5
Number of gaged sites: 1
Mean recurrence interval: 1.5 years

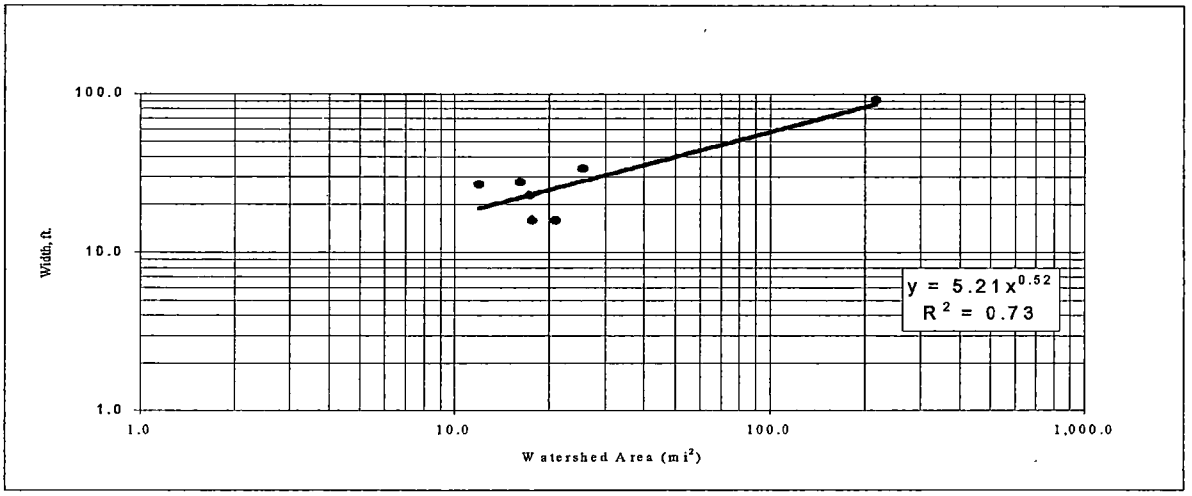
This region includes the arid landscapes around the Mimbres and lower Rio Grande Rivers and the Tularosa Valley sink. The topography is composed of mountain islands in a broad desert plain. The climate is extremely arid and the region dominated by ephemeral streams. Bankfull indicators were difficult to identify, especially in the ephemeral channels. With little vegetation to stabilize banks, consistent alluvial features were uncommon. A thorough understanding of the region's hydrology is further compounded by the extreme aridity. In many cases steep mountain channels flow out onto and infiltrate into the alluvial plain, often leaving no discernible stream channel. The channel data from the Mimbres and Dry Canyon appear to be consistent with statewide data. However, the three sites in the mountains to the west of Truth or Consequences, (E. Red Canyon, Morgan Creek, and N. Fork Palomas) fall consistently below the state trendlines. Similar data in the lower Pecos region suggest a lower regional curve may exist for the southern desert regions. The single gaged site had a bankfull discharge recurrence interval of 1.5 years.. A thorough local curve should be produced to verify bankfull stage in the channels of this region.

Table B6. Data for Lower Rio Grande Sub-Region.

Site Name	HUC	Region	WS Area (mi2)	XS Area (ft2)	Width (ft)	Mean Depth (ft)	Channel Type	RI (yrs)	Q (cfs)
Dry Canyon	13050003	Tularosa Valley	11.9	19.3	27.0	0.7	F4b		
N Fork Palomas	13030101	Lower Rio Grande	16.1	9.7	28.0	0.3	C4		
Morgan Creek	13030101	Lower Rio Grande	17.6	10.8	16.0	0.7	B4c		
E Red Canyon	13020211	Lower Rio Grande	20.9	13.0	16.0	0.8	C4		
Mimbres River at Mimbres, NM	13030202	Lower Rio Grande	216.0	94.5	92.0	1.0	C4	1.5	582

Figure B11. Data for Lower Rio Grande Sub-Region.





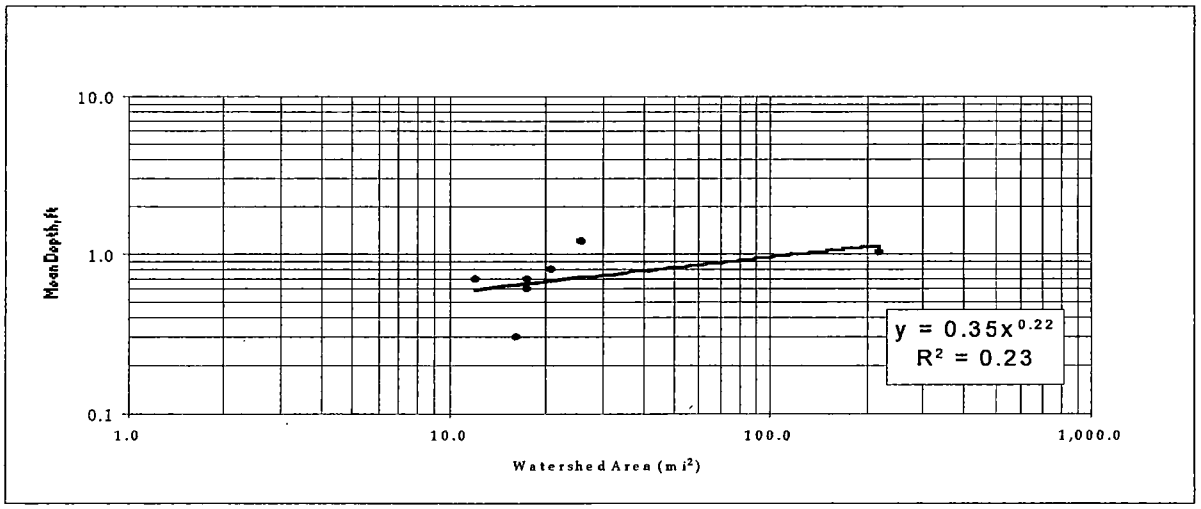
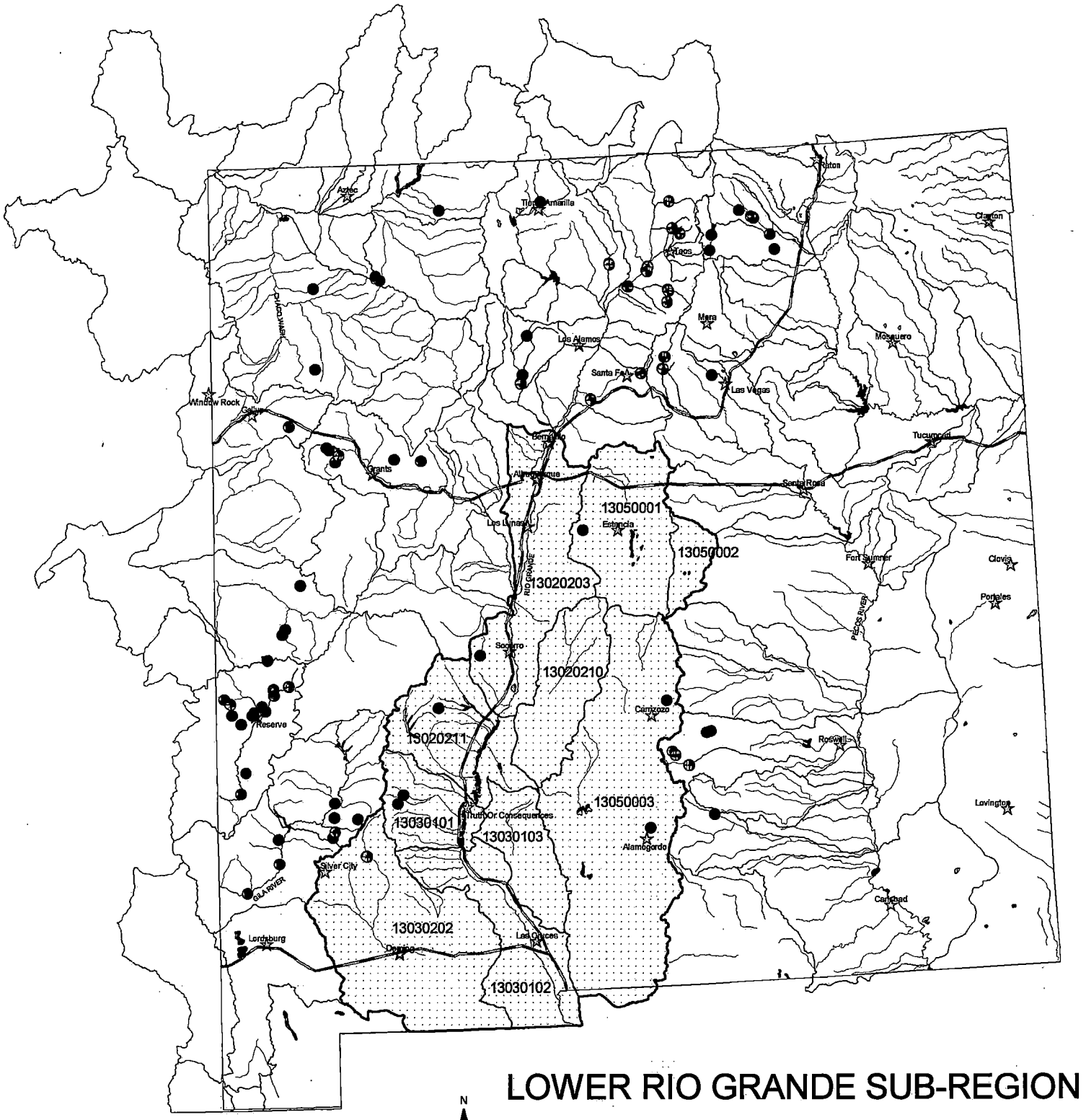


Figure B12. Map of Lower Rio Grande Sub-region



LOWER RIO GRANDE SUB-REGION

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- **Gage Survey Sites**
- **Bankfull Survey Sites**

SOURCE: EPA BASINS DATABASE

Appendix B7

Lower Pecos Sub-Region

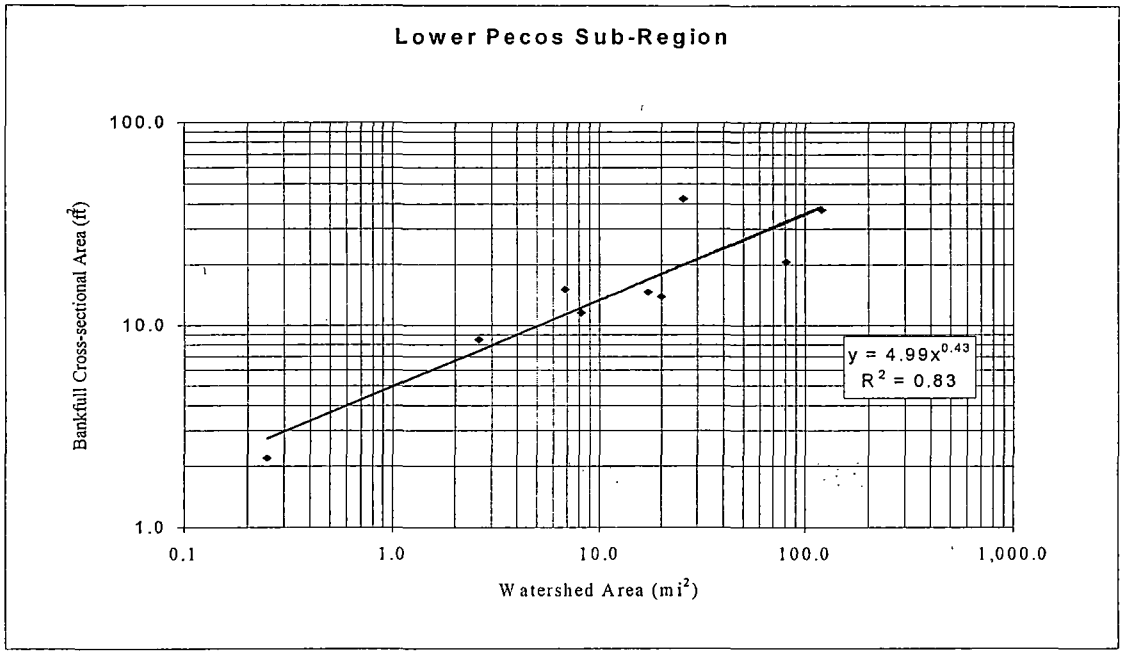
HUCs: 13060003, 13060005, 13060006, 13060007, 13060008, 13060009, 13060010, 13060011
Number of study sites: 8
Number of gaged sites: 2
Mean recurrence interval: 1.4 years

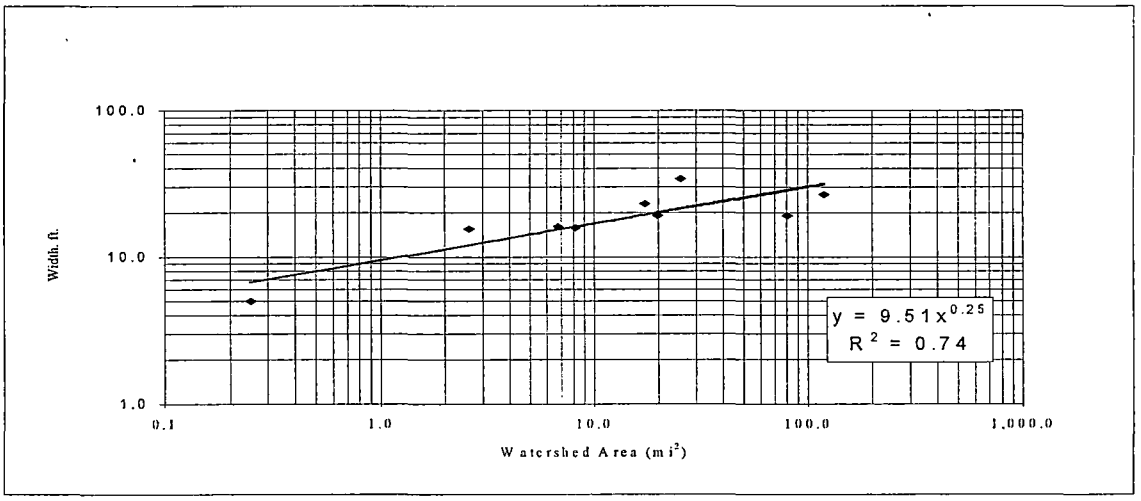
This region consists of mountain islands converting to arid grasslands along the lower Pecos River. It is divided into 8 Hydrologic Units and contains 8 study sites. The watersheds of this region generally begin in the mountains on the west and flow to the confluence with the Pecos River in the east. Although there can be snowpack in the higher elevations, these watersheds are dominated by single storm events that produce ephemeral channels and extremely short flow durations. Many of the perennial mountain streams are lost when they spread out onto the alluvial plain. Bankfull stage was very difficult to identify in the field. Alluvial features were small and disconnected. The data in this region demonstrates considerable scatter above and below the state trendline. This could be the result of difficulty in accurately identifying bankfull stage or could indicate that other bankfull relationships exist in this region. Similar data in the lower Rio Grande region suggests a lower regional curve may exist for the southern desert regions, however more data collection and analysis would be needed. Recurrence intervals from the 2 gaged sites were both approximately 1.4 years.

Table B7. Data for Lower Pecos Sub-Region.

Site Name	HUC	Watershed	WS Area (mi2)	X-S Area (ft2)	Width (ft)	Mean Depth (ft)	Channel Type	RI (yrs)	Q (cfs)
Eagle Creek Trib #1	13060008	Lower Pecos	0.3	2.2	5.0	0.4	A4a+		
Trib to Trout Ck on Hwy 15	13060008	Lower Pecos	2.6	8.5	15.5	0.5	F4		
V1 Canyon	13060008	Lower Pecos	6.8	15.0	16.0	0.9	C5b		
Eagle Creek Blo South Fork nr Alto, NM	13060008	Lower Pecos	8.1	11.6	15.8	0.7	B4	1.4	38
Sixteen Springs Canyon	13060010	Lower Pecos	19.9	13.9	19.0	0.7	B4c		
Rio Bonito	13060008	Lower Pecos	80.3	20.6	19.0	1.1	C4		
Rio Ruidoso at Hollywood, NM	13060008	Lower Pecos	120.0	37.3	26.7	1.4	B4c	1.4	152

Figure B13. Data for Lower Pecos Sub-Region.





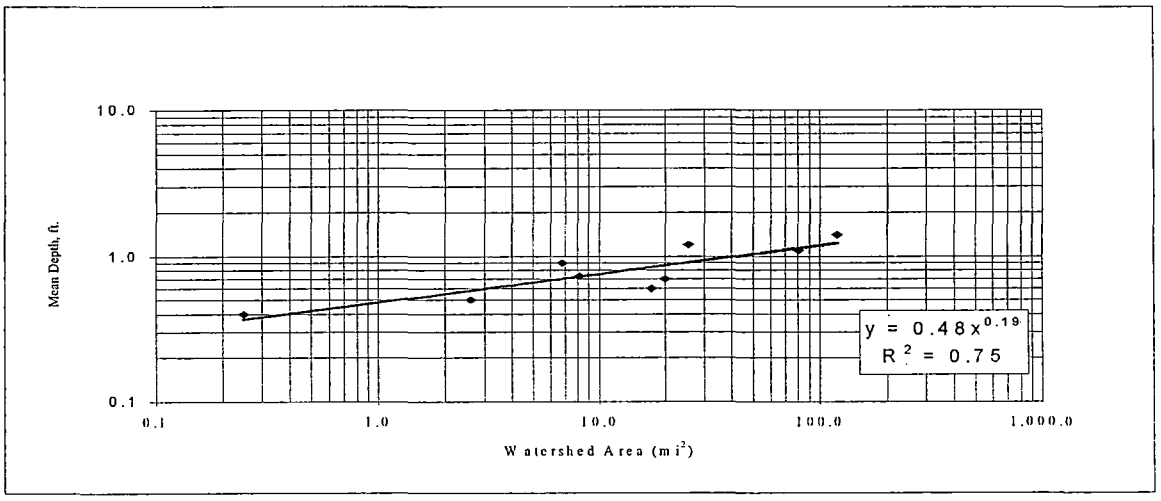
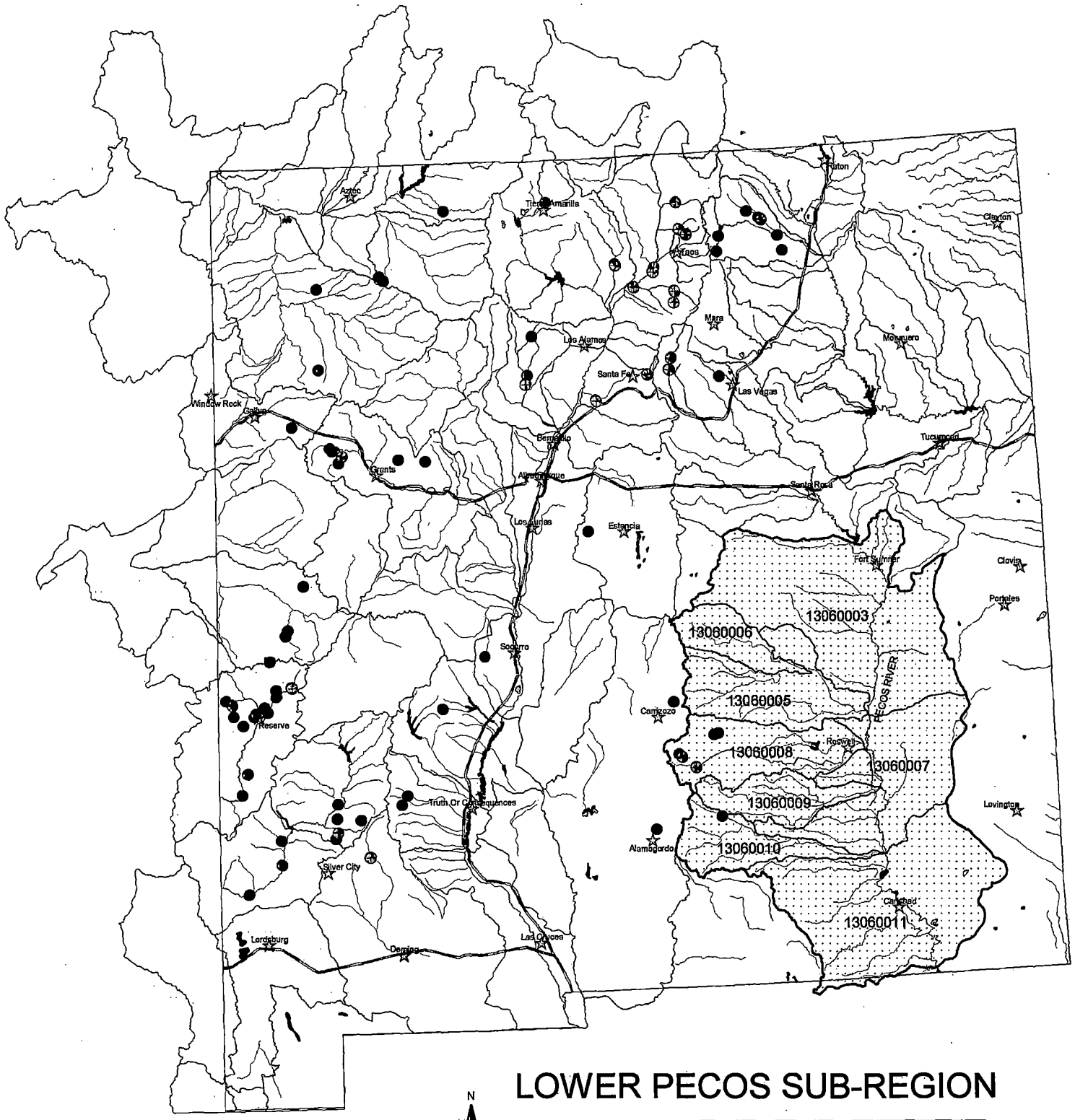


Figure B14. Map of Lower Pecos Sub-Region



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SOURCE: EPA BASINS DATABASE

Appendix C. Protocols for Gage Calibration, Use of Regional Curves, and Development of Local Curves.

1. Protocol for Gage Calibration

Preliminary Tasks

- Obtain USGS gage data: Ratings table, 9-207 forms, annual peak discharges, station description.
- Calculate flood frequencies for period of record.

Field Procedures

- Examine channel above and below gage and mark depositional features, other possible indicators of bankfull stage, terraces, and other features of interest.
- Survey a longitudinal profile that extends approximately 30-40 bankfull widths, including thalweg, water surface, bankfull indicators and other features, water surface at the gage, and gage benchmarks.
- Survey 3-5 representative cross-sections at riffle sites. If possible include a cross-section at or near the cableway or at the site of the reference cross-section for the gage. Extend the cross-section well above the active channel, including flood prone areas and, preferably, terraces. Note the longitudinal stationing (location along the longitudinal profile) of each cross-section.
- Photograph cross-section sites, gage, relevant depositional features, and other features of interest.
- Draw a site map.

Analysis

- Plot longitudinal profile for the thalweg, water surface, and bankfull surface, and cross-sections with noted bankfull elevations. Use field notes and photographs to assist in identifications. Confirm that bankfull elevations match for the profile and cross-sections.
- Calculate bankfull areas for each riffle cross-section and compare for consistency. This can be done with graph paper (count the squares) or with software such as AutoCAD.
- If there are inconsistencies in bankfull elevations or in channel cross-sectional areas, reconcile with field notes and/or photos.
- Determine bankfull stage at the gage, i.e. where bankfull profile line intersects gage (compare with gage benchmark elevations and/or water elevation at gage to get bankfull stage).
- Determine bankfull discharge from the ratings tables or curves (stage vs. discharge.
- Determine bankfull dischage return interval from the flood frequency analysis.
- Classify stream with Rosgen classification scheme.

Sources

Dunne, Thomas, and L.B. Leopold, 1978. Water in Environmental Planning. W.H. Freeman Co. San Francisco, CA.

Harrelson, Cheryl C., C.L. Rawlins, J.P. Potyondy, 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Technique. General Technical Report RM-245, U.S. Forest Service, Fort Collins, CO.

Rosgen, David L., 1996. Applied Fluvial Morhphology. Wildland Hydrology, Pagosa Springs, CO.

2. Protocol for Use of Regional Curves: Identification of Bankfull Stage in the Field

It is important to note that regional curves are not to be used as the basis for design. They are primarily a tool to assist scientists, engineers, researchers, land managers, and others working with stream systems in identification of bankfull stage in the field. Identification of bankfull stage can help in correctly determining channel forming or channel maintenance flows. Correct determination of these channel forming flows, coupled with reliable reference reach data, can then form the fundamental bases for subsequent design work, whether this relates to stream restoration, bank stabilization, protection of property, habitat enhancement, road and culvert crossings, or other types of work. Regional curves, used with local curves and reference reach information, can help in the design process.

Preliminary Tasks

- Determine the appropriate regional curve you will need for your location. If none exists, develop one from streams in that area (See Appendix C3).
- Determine the watershed area above the stream site at which you will be working.

Field Determination of Bankfull Stage

- Walk the channel and note features with consistent elevational relation to the channel, such as floodplains, point bars, vegetation, etc. It is important to thoroughly walk a sufficient length of the channel to cover a representative stream section.
- Walk the channel again, this time putting pin flags or other markers on the features that you have noted.
- Survey a cross section at a riffle reach (which has bankfull features) using a laser level (or other leveling instrument) and tape measure. Calculate the area of the cross section at the proposed bankfull stage. Area can be determined readily by plotting the survey data on graph paper, counting the squares and thus calculating the area. A quick estimate of area can be made in Arizona and New Mexico by multiplying maximum depth by 0.5 - 0.6 to estimate mean depth, and multiplying by bankfull width to get bankfull cross-sectional area. However, this estimate should be confirmed with actual measurements.
- Compare the cross-sectional area measurement with the values shown on the relevant regional curve. If there is good agreement, there is a strong probability that you have correctly identified bankfull stage. If there is disagreement in values, return to the site of the cross-section and look for other features that might represent bankfull stage and recalculate the area.
- Do this for at least two cross-sections to develop confidence in your bankfull determination. Use more cross sections if working in more difficult stream types, e.g. ephemeral or intermittent streams.
- To complete the survey of the site, measure the longitudinal profile of the stream reach, including thalweg, water surface, and bankfull features.

- Pebble counts can be done to provide a more thorough description of the channel.

Analysis of Data

- Plot the longitudinal profiles of the thalweg, water surface, and bankfull stage. The thalweg line will be quite uneven, reflecting riffles, pools, and bed features. The water surface line will not be as uneven as the thalweg line, depending on the stage, and the bankfull line should be relatively even, i.e. reflecting a fairly consistent slope.
- On the regional curve(s), plot cross-sectional area, mean depth, width, and discharge (if known) as a function of watershed area.

Sources

Dunne, Thomas, and L.B. Leopold, 1978. Water in Environmental Planning. W.H. Freeman Co. San Francisco, CA.

Harrelson, Cheryl C., C.L. Rawlins, J.P. Potyondy, 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Technique. General Technical Report RM-245, U.S. Forest Service, Fort Collins, CO.

Rosgen, David L., 1996. Applied Fluvial Morhphology. Wildland Hydrology, Pagosa Springs, CO.

3. Protocol for Development of Local Curves

Local curves are the same as regional curves but cover a smaller area, usually a stream reach of interest and other drainages in close proximity and nature. Local curves can provide more precise site-specific information than regional curves, and they can provide insight into channel stability and stable channel forms.

Preliminary Tasks

- Determine the area of the watershed draining into your site or reach of interest.
- Identify other drainages in the same area which have watershed sizes that bracket your watershed, and which also appear to have similar characteristics (e.g. precipitation, geology, elevation). Use at least five to six additional stream reaches for analysis.

Field Measurements

- Walk the channel of your site (and the other stream reaches) and flag important features, such as bankfull indicators and terraces.
- Measure the longitudinal profile of the stream reach, including thalweg, water surface, and bankfull features.
- Survey cross sections at 2-4 riffle reaches (which have bankfull features).
- Pebble counts should be done to provide a more thorough description of the channel.
- Draw site map and supplement with photographs.

Analysis of Data

- Plot the longitudinal profiles of the thalweg, water surface, and bankfull stage. The thalweg line will be quite uneven, reflecting riffles, pools, and bed features. The water surface line will not be as uneven as the thalweg line, depending on the stage, and the bankfull line should be relatively even, i.e. reflecting a fairly consistent slope.
- Calculate mean depth, maximum depth, width, and cross-sectional area for each cross-section, all referenced to bankfull stage, and determine average bankfull area, width, and mean depth as a function of watershed area.
- For all of the sites to be included in your local curves, plot bankfull area, width, mean depth vs. watershed area.